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# ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

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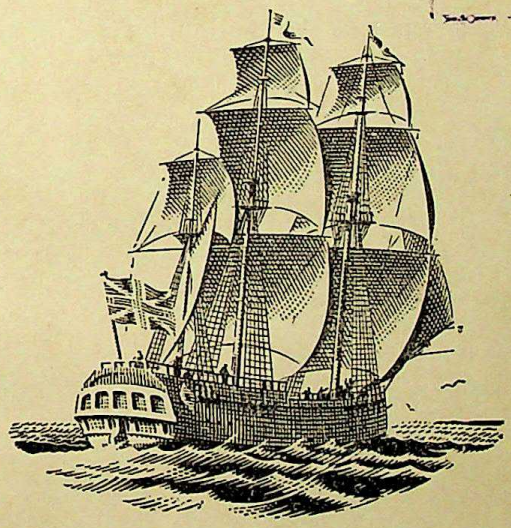

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# Carl Friedrich Gauss (1777–1854)

पुस्तकालय
गुरुकुल कांगड़ी विश्वविद्यालय
हरिद्वार

It is related that Laplace was once asked by Baron von Humboldt who, in his opinion, was the greatest mathematician in Germany. The reply not being what von Humboldt had hoped for, he asked 'But what about Gauss?', for he was at that time endeavouring to obtain the appointment of Gauss to the post of director of the Göttingen Observatory. 'Gauss?' answered Laplace. 'He is the greatest mathematician in the world!'

This was high praise of a young man who at that time was only 29 years of age, but subsequent events proved how correct Laplace was in his assessment. For Gauss became known as *mathematicorum princeps*, and he must be placed second only to Newton among the great mathematicians. There is a similarity between the two men in the early flowering of their genius, in the wide range of their discoveries, and in their mode of thought.

From a very early age Gauss showed a precocity in mental numerical calculation. Throughout his life he retained a prodigious power for mental calculation and a love of complicated numerical computation. It is said that he never had any need to refer to tables of logarithms. It is not surprising, therefore, that arithmetic and the theory of numbers became his favourite studies.

The first of his great masterpieces, the *Disquisitiones Arithmeticae*, was completed in 1798, when he was only 21 years of age, though the Leipzig printer's difficulties caused publication to be delayed until 1801. This work welded the theory of numbers, which previously had comprised a number of unrelated theorems, into a coherent and logical discipline and gave it a new direction. It is difficult reading, even for experts in the subject, for Gauss aspired to a classic perfection of style, and the line of reasoning by which he was led to his results is not apparent. It treats, among other matters, of the theories of congruences (and in particular of binomial congruences), of quadratic residues, and of binary and ternary quadratic forms. Some regard it as the greatest of his works; it was an amazing production for one so young.

The discovery by Piazzi at Palermo, on 1st January 1801, of the first of the asteroids, Ceres, presented Gauss with a problem that drew his attention for a time away from the higher arithmetic. Ceres could be observed only for a few weeks before it was lost to view. Unless its orbit could be computed there was a probability that it would not be rediscovered. In theory, three observations of the position of a planet or comet suffice to determine its orbit, but the problem of deriving an orbit from a short arc had never before arisen. Gauss developed a method of solution, calculated the orbit of Ceres, and correctly predicted where it would be found. The method used was extended into a thorough discussion of methods of determining planetary and cometary orbits, including the analysis of perturbations, and was published in 1809 under the title *Theoria motus corporum coelestium in sectionibus conicis solem ambientium*; the methods used today are essentially based upon it.

But the whole of his energies was not absorbed by these problems. He was the first to give a coherent account of complex numbers and to interpret them as labelling points on a plane; he enunciated in a letter to Bessel the fundamental theorem in what is now called the analytic functions of a complex variable, a result which he did not publish and which was later rediscovered by Cauchy; and he proved that every numerical equation has a real or imaginary root.

Another great work was on the hypergeometric series. Infinite series had been used by mathematicians without any examination of the conditions under which they are convergent. Gauss determined the conditions for the convergence of the hypergeometric series, which as special cases include many of the important series in analysis. For the first time, he imposed rigour on analysis, and thereby revolutionized its methods.

The important memoir on biquadratic reciprocity broke entirely new ground. Here were introduced what are now termed the Gaussian complex integers, thereby bringing complex numbers for the first time into the theory of numbers and inaugurating a general theory of algebraic numbers.

The appointment of Gauss as scientific adviser to the Danish and Hanoverian governments in connection with an extensive scheme of triangulation, including the measurement of an arc of meridian, not only provided him with scope for dealing with extensive masses of numerical data but renewed his interest in the theory of errors and the adjustment of observations. He had invented the method of least squares when he was 18. This method, based on the Gaussian law of distribution of random errors, is extensively used in all branches of science, and especially in astronomy and geodesy. Two important memoirs, *Über Gegenstände der höhern Geodäsie*, appeared in 1843 and 1846



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respectively. The memoir on *Theoria combinationis observationum erroribus minimis obnoxia* had appeared earlier. The surface of the Earth being curved, Gauss was led to consider the general problems connected with curved surfaces, such as the properties of geodesics and the definition of curvature. He introduced the parametric representation of surfaces, which is independent of extraneous axes, and thereby laid the foundations of differential geometry. He developed the method of conformal mapping in which angles are preserved, using the theory of analytic functions of a complex variable.

About 1830 Gauss began to take an interest in the problems of the Earth's magnetism. With Weber he invented the declinometer and the bifilar magnetometer. In 1833 appeared the memoir *Intensitas vis Magneticae Terrestris ad Mensuram Absolutam Revocata.* He erected a magnetic observatory in Göttingen for the study of the changes of the Earth's magnetism and formed a Magnetic Association for obtaining observations at prearranged days at a number of stations. Two important memoirs, *Allgemeine Theorie des Erdmagnetismus* and the *Allgemeine Lehrsätze*, appeared in 1838 and 1839; these included the harmonic analysis of the Earth's magnetic field and a general theory of forces attracting according to the inverse square of the distance. Very appropriately, the unit of magnetic intensity is named the gauss.

Another important memoir, *Dioptrische Untersuchungen*, published in 1840, gave a general theory of optical systems, to permit of the determination of the image of any object in any system. This memoir introduced the conception of the six cardinal points, the two focal points, the two nodal points, and the two principal points, which are often called the Gaussian points.

Limitations of space prevent reference being made to all of Gauss's work, for he made important contributions to almost every branch of mathematics. The subject of non-Euclidean geometry began with him. While still at school he had felt the need to examine the postulates of Euclidean geometry and had found that a geometry could be developed without the postulate of parallels. He subsequently showed that perfectly self-consistent results could be obtained without it. The theory of determinants, the calculus of variations, and the theory of elliptic functions were other subjects to which he contributed.

It is amazing that one man could make contributions of such importance and of such originality to so many different subjects. It was indifferent to Gauss whether he was working in pure or in applied mathematics. Every subject that he touched he adorned. He developed new branches of mathematics, and to others he gave a new direction and a new stimulus.

# In memoriam: Sir Wallace Akers (1888–1954)

With profound regret we record the death on 1st November, 1954, of Sir Wallace Akers, who was a member of the editorial advisory panel of ENDEAVOUR until ill-health necessitated his retirement last year. His death will be felt as a personal loss by all concerned with the publication of ENDEAVOUR, for despite the eminence to which he attained he remained the most approachable of men. Those who sought his advice always found wise counsel, and were made to feel that the problem to be discussed, whether trivial or otherwise, was absorbing his whole attention. A good listener when the occasion called for it, he was also a great conversationalist. On the editorial advisory panel his capacity of dealing with equal facility with points of detail and points of general principle was invaluable.

Sir Wallace Akers was born on 9th September, 1888, and was educated at Aldenham School and at Christ Church, Oxford. From the University of Oxford, which conferred an honorary degree upon him in 1952, he went straight into the chemical industry, with which he was closely associated virtually all his life. From Oxford, in 1911, he joined Brunner, Mond and Company Limited, one of the founding companies of Imperial Chemical Industries Limited. Apart from a brief period spent in the Far East, and a short time as director of British atomic energy research, the whole of the rest of his working life was spent with Imperial Chemical Industries, of which he became a director in 1941. In that year he was seconded to the Department of Scientific and Industrial Research to take charge of the British atomic energy project. In this capacity he did work of great national importance, for which he was knighted. He retired in 1953, but for him retirement implied a direction of his energies into new channels rather than any diminution of them, and his death is a very great loss to science and to the public service. He was known throughout the world not only as an eminent scientist but as a most lovable man.



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# The riddle of influenza virus

SIR MacFARLANE BURNET

Growing knowledge of the influenza virus leads to the conclusion that while this has distinct antigenic, enzymic, and genetic properties, it is at the same time chemically indistinguishable from fragments of the cytoplasm of the cells in which it is a parasite. This conclusion is of fundamental importance, not only in devising new methods of attacking what can be a very deadly disease but for understanding the structure and function of the vertebrate cell.

For the last ten or twelve years influenza virus has been a favourite object of study for those who are interested primarily in the nature of viruses rather than in the diseases for which they are responsible. This virus has two qualities which make it particularly suitable for such studies. The first is that it can be grown very readily in the cavities of the chick embryo, the allantoic fluid of which then provides a relatively concentrated and conveniently handled form of virus. A second, and even greater, advantage to the experimenter is that the concentration of virus in such fluids can be accurately and simply titrated in the test-tube by utilizing the virus's power of agglutinating red blood cells—the haemagglutination phenomenon of G. K. Hirst.

These properties facilitate investigations necessary to establish the physico-chemical nature of the virus particles and to determine, at least in outline, the course of their multiplication in the cell. These investigations have in fact been made, and at least as much is now known about the nature and activities of a typical influenza virus, such as the standard American strain PR8, as about any other animal virus. As this knowledge accumulated, there gradually became clear the paradox with which this article is concerned—that although the particles of influenza virus are well-defined, functional units with characteristic antigenic, enzymic, and genetic qualities, chemically they cannot be differentiated from fragments of the cytoplasm of the cells in which they are parasites.

## THE FUNCTIONAL ACTIVITIES OF THE VIRUS PARTICLE

Influenza viruses are nowadays defined, and even named, on the basis of their reaction with vertebrate red blood cells, a reaction normally manifested as haemagglutination; the virus particles themselves are the agglutinating agents. When virus, in the form of allantoic fluid from an infected chick embryo, is mixed with a red-cell suspension, the virus particles stick firmly to the cell surfaces; since one virus particle can, if conditions are suitable, be adsorbed simultaneously by two cell surfaces, a whole series of bridges between the red cells is rapidly developed. The cells become tied together into visible aggregates, which rapidly clump. With a concentrated virus such a suspension is very quickly converted into a clear supernatant fluid and a mass of agglutinated cells, the latter often producing rather characteristic patterns by adhesion of the altered cells to the hemispherical bottom of the test-tube. This condition is, however, not permanent. If the mixture is kept at 37° C, and is reshaken every thirty minutes, it will be found that the cells take progressively longer to settle and that the clumps are smaller. After two or three hours, the cells may become as stable in suspension as normal cells. Experiment shows that the virus has been released from the cells, which have lost all their capacity to adsorb, or to be agglutinated by, the virus.

Study of this phenomenon has shown that it is the result of a specific interaction between components of both the virus surface and the cell surface. The interaction has most of the characteristics of enzyme action, and can best be regarded as an unusually slow type of action of this kind, in which the intermediate union of enzyme and substrate, postulated for all enzyme actions, is a conspicuous feature.

In 1947 the substrate of the virus enzyme was identified as a mucoprotein, and all subsequent work has confirmed this opinion. Several mucoprotein substrates of influenza virus enzyme have now been prepared in pure form, the degree of purity being judged by the very rigid tests of the production of a single peak in the electrophoresis pattern and a shift of the peak as a whole (indicating a lower electrophoretic mobility of the



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component) when the preparation is treated enzymically with the virus. Gottschalk has recently made some noteworthy advances in isolating and characterizing the split product resulting from the reaction and in defining the probable nature of the prosthetic group with which the virus enzyme reacts. This, however, is not relevant to our immediate theme, which is the specificity of reaction of the influenza viruses. In the field of adsorptive-enzymic reactions this specificity is best shown in the phenomena of the receptor gradient.

### THE RECEPTOR GRADIENT

The simplest way of demonstrating the nature of a receptor gradient is to take a suspension of washed human red cells and to treat portions of it with the enzyme prepared from filtrates of *V. cholerae* cultures, an enzyme which Burnet and Stone [1] have called RDE (receptor-destroying enzyme). This enzyme appears to be isodynamic with the enzymes of the viruses of the influenza group. By the graded action of the enzyme one can prepare a series of cell suspensions which are progressively less readily agglutinated by viruses. If a comprehensive series of viruses is tested for power to agglutinate these cells, they will be found to fall into linear order. Newcastle disease virus (NDV) is the first to lose its power to agglutinate, and, in our standard series, the influenza B strain MIL is the last. Parallel to the loss of agglutinability there is a progressive fall in the electrophoretic mobility (EPM) of the cells, and Ada and Stone [2] have shown that the point at which agglutinability by each virus is lost can be defined in terms of the EPM of the cells.

Without going into further detail, it can be said that by these techniques it is possible to demonstrate a specific and reproducible characteristic of each strain of influenza virus. The favoured interpretation is that the actual enzymic group is common to all the viruses and to RDE, but that for each virus there is a characteristic pattern of atomic groups surrounding each enzymic unit and modifying the ease with which contact with substrate groups, of varying degrees of accessibility, may be made. The regularity of the results implies that these patterns have some individual specificity for each type of virus.

### ANTIGENIC CHARACTER

Uncomplicated influenza is a self-limiting disease, which is probably brought to an end by the development of active immunity, marked by the appearance in the blood of neutralizing antibody that can be experimentally detected. No one has two attacks of the same kind of influenza in a single epidemic, and the whole modern approach to the epidemiology of influenza is based on recognition of the immunological character of the strains of virus which are responsible for successive epidemics. The most practical approach to the study of these differences is by the use of antihaemagglutinin (AHA) titrations. If to a series of dilutions of convalescent serum—obtained from a human patient or an infected ferret—a standard amount of virus is added, the power of the virus to agglutinate red cells is destroyed by all concentrations of serum above a certain minimum. This allows one to express quantitatively, as its AHA titre, the power of the serum to inactivate any given influenza virus. There are important technical precautions needed to avoid confusion with some types of non-specific inhibition of haemagglutination, but if these are taken it is possible to obtain a clear pattern of antigenic relationships between the various types of influenza virus that have appeared and been isolated since 1933. The most important study of this type, due to Hirst [3], shows that seven specific antigens successively appeared in influenza A strains between 1933 and 1951. In addition, there are antigenic factors that are common to some or all types. Occasionally a strain may change its antigenic character in the laboratory, usually as a result of transfer to a new host. However, if strains are maintained solely by chick-embryo passage they remain constant in their immunological behaviour. Since such precautions have been taken it has been found that, in any given year in which influenza has been widely prevalent throughout the world, only one, or at most two, antigenic types of virus have been involved.

The antigenic specificity of the virus is, then, a well-defined, functional character of vital importance for both the survival of the virus in nature and the epidemiologist's understanding of the disease it causes. Since antibody can be removed from a serum by treating it with large amounts of influenza virus, the antigens concerned must lie on the surface of the virus. They have not been isolated as pure chemical substances, but by every analogy with other phenomena in the same class they must be protein molecules possessing an individual pattern of atomic configuration that serves as the antigenic determinant. These patterns are quite distinct from any such patterns in the proteins of the host species and also from the protein patterns of serologically



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distinct influenza viruses. It is not possible to say whether or not they are related to the complex of enzyme and associated groupings that are concerned in the phenomena of the receptor gradient.

### GENETIC INDIVIDUALITY

All the characteristics of influenza viruses which are reproducible from generation to generation must necessarily have a genetic basis. The systematic study of genetic characters in animal viruses has, however, only recently been undertaken. Such work becomes possible when we have available a means for isolating and maintaining pure clones of virus; a series of conveniently demonstrable genetic markers, by which pure clones of different hereditary constitution can be characterized; and a technique by which genetic interaction between two different strains can be allowed to occur. These requirements have been fulfilled for some time in regard to the bacterial viruses, and a major activity of the writer's own laboratory has been to develop a similar approach to the influenza viruses. We believe that we now have adequate technical methods for demonstrating that a number of well-marked genetic interactions can take place between influenza virus strains. In the system that we have studied most intensively—namely the interactions of various substrains of the classical influenza A strains, WS (Hampstead 1933), and MEL (Melbourne 1935)—the results indicate far-reaching recombination involving two distinct linkage groups. Four 'markers', i.e. differences between strains, are located in one linkage group, three others in the second. Without attempting to go into detail, which may be found in papers by Burnet and Lind since 1951 [4], the type of result may be indicated as follows. If we call the markers of MEL strain A, B, D, F and C, E, G respectively, and those of the neurotropic variant of WS a, b′, d, f and c, e, g, the following recombinations have been obtained:

| | | |
|---|---|---|
| ABDF: ceg | ABDF: ceG | ab′df: cEG |
| abdf: CEG | abdf: ceg | aB′df: cEg |

Each of these represents a true-breeding type available in the form of a pure clone. Rather different rules hold in regard to the transmission of virulence when recombination occurs between a highly virulent and a non-virulent strain. It is usual to find among the progeny strains at any one of several intermediate degrees of virulence, with or without interchange of other 'marker' qualities.

Here, however, there is no need to discuss the details of influenza virus genetics. All that is needed is to make clear the existence in influenza virus of a complex genetic mechanism, which we consider to show fairly clear analogies with the genetics of bacterial viruses on one hand and with the genetics of bacteria on the other. Qualities can be transferred as units which behave in all essentials like the genes in higher organisms. Experience with influenza virus would lead one to postulate not less than twenty genes per virus genome. In addition there is cogent evidence that each morphological virus particle may have one, two, three, or more genomes, perhaps with two as the usual average.

These genetic qualities must have a physical basis, presumably a molecular pattern in nucleic acid. The most recent work, by Ada, on the nucleic acid content of purified influenza virus indicates that there is no deoxyribonucleic acid (DNA) present as an integral part of the influenza virus particle; the genetic behaviour must therefore depend on the 0·8 per cent of ribonucleic acid (RNA) known to be present. This, incidentally, gives a greatly increased importance to these genetic studies of influenza virus, since they relate to the only known system, capable of genetic analysis, in which deoxyribonucleic acid can play no part.

To summarize, we have in the viable influenza virus particle a complex, well-defined system. Each type has its own functional characteristics, which can be defined in terms of the interaction of virus with cell surfaces and with the specific mucoproteins that serve as substrate for the interactions; of the antigenic qualities of the virus; and of the virulence of the strain towards different cells and organs. With some qualifications in regard to virulence, all these characters are maintained on passage, under optimal conditions, in the allantoic cavity. Again with some minor qualifications, differences between related strains can be shown to be determined by genetic units of the same general quality as the genes of higher organisms. We can, then, be quite dogmatic in classing the influenza virus as an organism with elaborate patterns of functional activity similar to those of other organisms. With this conclusion in mind we can examine the physical nature of this functioning organism.

### THE PHYSICAL QUALITIES OF INFLUENZA VIRUS

The virus particles can readily be separated from infected allantoic fluid by fractionation in the ultracentrifuge and by repeated washing;


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their morphology can be examined under the electron microscope (figure 1) after fixation and shadowing by the conventional techniques. With well adapted stock-strains most of the particles appear in more or less spherical form, some being flatter than others. Their mean diameter is around 110 mμ, with a fairly wide scatter of individual values. In addition, one always sees rodlets, apparently made up of from two to four fused spheres. The spherical units themselves are by no means uniform in diameter, and a careful examination of a good electron micrograph impresses one with the reasonableness of the conclusion, based on genetic evidence, that particles may carry one, two, or three sets of genetic units. The range of sizes could well represent masses ranging from one to three arbitrary units. In these old stock-strains the long filaments which are such a feature of recent strains are absent or very rare.

The evidence that the spheres we see in electron micrographs do in fact represent the infective virus particles can be accepted as complete. Appropriate experiments have shown that the units carrying the infectivity are deposited by the ultracentrifuge, and are held back by filters, as if they were 100–120 mμ in diameter. They are adsorbed by, and eluted from, red cells just as the visible particles are (figure 2). What is still uncertain is whether all the particles which can be seen are 'complete', in the sense of being able to enter a susceptible cell and induce infection, giving rise to like units capable of indefinitely carrying on the chain of infection and multiplication. It is well known that if virus is not produced under carefully controlled optimal conditions many of the particles are in fact not infective in this sense. With optimally prepared virus, current estimates suggest that only between a half and a tenth of the particles present can initiate continuing infection.

One may summarize the morphological findings by saying that the visible particles show a rather wide range in size and shape, but that we are clearly concerned with a relatively homogeneous population of biological units and not, for example, with a more or less random accumulation of cytoplasmic fragments from damaged and disintegrating cells.

### CHEMICAL COMPOSITION OF INFLUENZA VIRUS

It is not particularly difficult to prepare a few milligrams of influenza virus by standard techniques, but it is far from easy to satisfy one's critics that any given preparation contains no significant proportion of material other than influenza virus particles. All the available data on the composition of influenza virus are based on the assumption that the appropriate technique—which usually involves adsorption on, and elution from, red cells, followed by a sequence of purifications in the ultracentrifuge—does in fact give a virtually pure suspension of influenza virus.

The composition of such virus has been studied in a number of laboratories, with results that are broadly consistent except with regard to the vital matter of nucleic acid content. There is sufficient variation in the results, however, to suggest that none of the analyses are accurate to more than one significant figure. Nor, despite the figures given in the literature, does one yet feel justified in accepting claims that there are significant differences in the composition of different strains of influenza virus. With these reservations, one may tabulate the observations on the chemical composition of purified influenza virus. Physical measurements suggest a water content of around 40 per cent, and this must be remembered in any consideration of the chemical findings, which are expressed in terms of the percentage composition of thoroughly dried material.

*Chemical constitution of dried influenza virus*

| | *per cent* |
|---|---|
| Elementary analysis: | |
| Carbon | 52 |
| Nitrogen | 9·5 |
| Phosphorus | 0·9 |
| Lipids (23 per cent): | |
| Phospholipid | 11 |
| Cholesterol | 5 |
| Neutral fat | 7 |
| Protein | 65 |
| Carbohydrate | 10 |
| Nucleic acid (ribonucleic acid) | 0·8 |

Some of these figures call for comment. The carbohydrate value is much higher than would be accounted for by the ribose of the nucleic acid, and according to Knight [5] mannose, galactose, and hexosamine are present. These are precisely the components that are present in all the mucoproteins with which influenza virus reacts enzymically, and there is necessarily a rather strong suspicion that the carbohydrate has been derived directly from the host cell and may not be an intrinsic part of the virus particle.

The lipids present are also of the same general character as those to be found on the surface of the cell of any vertebrate. The given total of 23 per cent is from Taylor, Sharp, *et al.*, and higher



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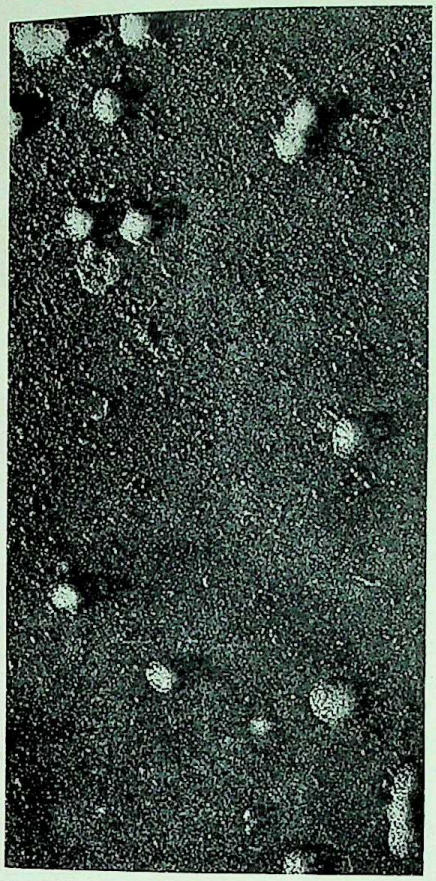

FIGURE 1 – *Electron micrograph of purified influenza virus, showing the moderate degree of variation in size and shape.* (× 20,000)

FIGURE 2 – *'Ghosts' of fowl red cells on which particles of Newcastle disease virus (closely related to influenza virus) have been adsorbed.* (× 3,200)

FIGURE 3 – *A receptor substance—macromolecules of the urinary mucoprotein which can serve as receptor substance and as substrate for the influenza virus enzyme.* (× 30,000)

*Electron micrographs by R. F. Mitchell and G. L. Ada, previously unpublished.*

values have been obtained by others. It is interesting in this connection to note Cohn's [6] finding, reached by adding labelled phosphorus to chick embryos, that the chief effect of infection by influenza virus is to increase greatly the uptake of phosphorus into the phospholipid fraction.

Analyses of amino acids from influenza virus protein have been published, but, as would be expected, they show the same type of distribution as is found in cell extracts. The most important finding in relation to the protein is that a significant proportion (20–30 per cent of that present on the virus surface) reacts immunologically with sera prepared by immunizing rabbits with the corresponding host-cell extract. Purified egg virus reacts with an anti-embryo extract serum; purified mouse virus with an anti-mouse serum. It has never been clearly established, and perhaps never will be, whether this activity is due to contamination with host protein or whether it is due to protein actually incorporated in the virus particle.

The nucleic acid content of the particles is a matter of controversy, primarily because of the very considerable technical difficulty of estimating small amounts of nucleic acids in complex material containing sugars and phosphorus-containing substances other than nucleic acid. By combining three different approaches—relating respectively to the nature of the sugar in extracted nucleic acid, phosphorus estimations after exhaustive lipid extraction, and ultra-violet absorption curves—Ada, in Melbourne, has concluded that the amount of DNA present is far less than one molecule per virus particle, and that the total nucleic acid is considerably less than that claimed by previous workers. His estimate is 0·8 per cent of RNA.

If we now look over the physical and chemical characters of influenza virus as outlined above it becomes very difficult to quarrel with Bauer's phrase that the influenza virus is 'merely a fragment of diseased cytoplasm.' Virtually the only


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quality that distinguishes it at the physico-chemical level is the morphology of the particles. If they are to be looked at as fragments of host-cell cytoplasm, then we must admit that they are fragments of material within which a new and significant structural reorganization has occurred.

Relatively little work on the development of morphological units in the infected cell has been reported. The two groups of American workers who have studied thin sections of embryonic cells by electron microscopy agree that no internal structures can be seen in the early stages of infection, the only abnormality being the accumulation of spheres and filaments along the free edge of the cell. In their view, influenza virus particles are either 'created' by the extrusion of suitably organized portions of the cell's surface, or the process of intracytoplasmic development of new virus particles produces no visible disorganization of the cytoplasm. With the related, but more highly pathogenic, viruses of Newcastle disease and fowl plague there is visible damage to cytoplasm and mitochondria in unsectioned tissue-culture cells. Flewett and Challice observed long filaments in the cytoplasm, from which fowl plague virus particles appeared to develop by fragmentation. Because of the method used, however, it is not certain that the filaments observed were actually in the cytoplasm and not already on the surface.

### THE DEVELOPMENT OF INFLUENZA VIRUS IN THE HOST CELL

Many points about the intracellular multiplication of influenza virus are still obscure, and it is possible that the current picture may need fairly radical alteration if some of our assumptions about the quantitative relationship between haemagglutinin and infectivity titres and numbers of virus particles should be found to be erroneous. However, at the present time there seems to be good evidence for the following sketch of what happens when a virus particle enters and initiates infection in a susceptible cell of the allantoic cavity.

The first step is the adsorption of virus by some of the mucoprotein 'receptors' of the cell surface (figure 3). Once attached, it is probably folded into the cytoplasm by a process analogous to the wetting of a dust particle by a drop of water. In the cytoplasm an interaction between virus and some part of its environment initiates a process by which the virus particle disappears as a demonstrable entity. Using a little imagination, and some hints from the behaviour of the bacterial viruses, we can picture an unfolding of the particle, allowing its genetic elements to make effective contact with the cell components that will guide in the energy and substance needed for their replication. No virus is detectable for three to four hours after entry, and during this period we must postulate a process of rapid multiplication of genetic elements. Their replication is probably for the most part as independent 'linkage groups', although the genetic evidence points also to the possibility of independent replication of smaller genetic blocks or units. The elucidation of the relationship between genetic replication and the reproduction of what may be called the somatic qualities of haemagglutinin and antigen is a major problem for the future. It has been suggested that the complex of genetic units with protein-synthesizing elements of the host cell containing RNA could well be equated with the 'soluble complement-fixing antigen' which is produced in relatively large amount in infected cells. This, however, may represent a 'confusion of categories' and is probably unacceptable to most virologists. Whatever the process, after about four hours new infective and haemagglutinating particles are demonstrable within the cells, and a little later they begin to be released into the environment. The process of liberation does not resemble the explosive release of virus from an infected bacterium. It is a process which reaches its peak two or three hours after the first appearance of virus and may continue for perhaps as long as twenty-four hours (a total of about 100–200 descendant virus particles per cell being released). Gross damage to the cell does not become apparent until some hours after the period of most active production and liberation of virus. Under a variety of mildly disadvantageous conditions the new brood of virus contains a proportion (sometimes more than 99 per cent) of 'incomplete' virus, which can agglutinate red cells but cannot induce typical infection of fresh susceptible cells.

### CONCLUSION

This outline of the properties and behaviour of one of the simplest of all living organisms must necessarily be very incomplete, but even within the framework of what we know already it seems to present an important lesson for general biology. That lesson is the significance of pattern. Considered apart from the specific patterns carried by the macromolecules concerned, any type of influenza virus particle is like any other, and distinguishable from a fragment of host-cell cytoplasm only by a moderate regularity of size and



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shape. Some of the proteins, however, have new specific patterns replacing—or perhaps additional to—the patterns characteristic of host proteins, and we can feel certain that the vital 0·8 per cent of RNA carries a code that differs sharply from that of the cytoplasmic RNA from which it must be derived. The possibility that the large amount of lipid in the particle also has its own series of specific patterns is something that must await the emergence of the appropriate technical approach. On this view, then, the influenza virus is no more than a fragment of living matter carrying patterns —patterns which determine whether the particle is, like most laboratory strains, virulent only for the chick embryo or, at the other extreme, capable of initiating a deadly pandemic like that of 1918.

In the last analysis, molecular pattern is a strictly chemical concept, and in the case of antigenic specificity the actual groups responsible for determining antigenic pattern have been defined in a number of artificial antigens. Landsteiner and Pauling are the two names that come first to mind in connection with this development. The enzymologists have been much less successful. Most of the enzymes liberated for specific functions have now been purified and crystallized. Much has been learnt of the specificity of enzymic action in terms of the chemical structures which can or cannot be split, and do or do not act as competitive inhibitors of enzymes. Yet, just as we have no alternative to speaking of the specific aspect of antibody as the 'complementary aspect' of the known or unknown determinant of the corresponding antigen, so we are equally compelled to speak of the essential enzyme structure as a (perhaps slightly distorted) chemical pattern, complementary to the specific substrate grouping. Where we have to deal with natural antigens—as in pathogenic micro-organisms—or with the all-important sequences of enzymic action within the cell, we are reduced simply to making the best use we can of purely functional concepts.

We have a clear indication that single genes may, or perhaps must, be specifically related to functional protein patterns expressible as antigen or enzyme. The great bulk of genetic work on organisms more complex than bacteria and moulds is, however, concerned with the systematization of the inheritance of morphological and functional characters, which are quite beyond any chemical definition. The characteristic type of generalization is the chromosome map, a pattern that may, in the last analysis, represent another pattern in the arrangement of purines and pyrimidines in a macromolecular chain of DNA, but which is most unlikely ever to be so transcribed. With all respect to the triumphs of the biochemical approach, it is becoming more and more evident that the understanding of the basic processes of biology may need an entirely different approach, based on sequences of significant patterns.

It may be that the next development of 'communications theory' will be in the heart of the cell, where 'information' seems to flow steadily from the genes to the functional and productive divisions of the cell, through chains of patterned macromolecules; no doubt the inevitable 'feedback' controls are similarly mediated. In many ways the most effective way of picturing the activity of the influenza viruses, and perhaps of many other viruses, is to think of them as a set of punch-cards maliciously inserted into vital parts of a fantastically complicated computing machine. An essential part of the machine's activity is to produce, also in the form of punch-cards, new programmes for its own functioning. Something analogous to virus action would result when the machine found itself compelled to produce programmes that would lead inevitably to its malfunction or destruction.

A completely adequate justification for research on influenza virus is to be found in its importance as a cause of human disease. Yet at the present time there is perhaps more significance attaching to the quest for an understanding of the nature of its attack on the susceptible cell. To the biologist an animal virus is pre-eminently a probe for exploring the structure and functioning of the vertebrate cell, and with the growing development of ideas of specific pattern it becomes of special importance. It may not be wholly a fantasy to say that in influenza virus we have a tool—a uniquely suitable tool—with which to break some of the codes that lie at the basis of cellular life.

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# The first English microscopist: Robert Hooke (1635–1703)

CHARLES SINGER

Hooke's genius for mechanical experiments is widely known, but his brilliant biological work is much less appreciated, perhaps because almost all of it was done within the brief space of two years. His *Micrographia* of 1665, a number of illustrations from which are figured here, was not only an outstanding work in itself but of very great value in stimulating the work of his contemporaries—notably Grew, Malpighi, Swammerdam, and Leeuwenhoek.

The earliest observations with the aid of the compound microscope, invented by Galileo, were made by his fellow members of the 'Academy of the Lynx,' and notably by its president Federigo Cesi (1585–1630) and its secretary, Francesco Stelluti (1577–1653), between 1611 and 1624 [*Endeavour*, **12**, 197, 1953]. During the next few years these records were somewhat amplified, but they excited very little scientific interest. From 1625 to 1665 is an almost blank period in the history of micrography. Except for certain observations on the capillary blood vessels, made by Malpighi about 1661, nothing very significant appeared until the publication by Robert Hooke (1635–1703) of his great *Micrographia* (London, 1665). Production of this was stimulated by the newly founded Royal Society in England, somewhat as Stelluti and Cesi's *Apiarium* was elicited by the short-lived *Accademia dei Lincei* in Italy. Unlike the *Apiarium*, however, Hooke's *Micrographia* attracted wide attention, was much read, and became at once a classic of the 'New Philosophy' which we now call 'Science'.

There is general appreciation of the mechanical skill, inventive genius, and extraordinary scientific insight of Robert Hooke. These qualities of his need no discussion here, for they have been considered by E. N. da C. Andrade. Hooke's other talents have, however, been less noticed, and here we consider his exceptional capacity as an observing naturalist.

Galileo and his successors had riveted men's attention on the vastness of the universe, as the telescope revealed star beyond star, and the times were full of wonder at such things. But in 1665 men had had no experience of the world of complex living things of extreme smallness which Hooke was the first to explore in any detail. As to structures so small as to be beyond the reach of vision, there had hitherto been nothing but speculation. Hooke's *Micrographia* of 1665 was a messenger from the newly revealed minute world, as Galileo's *Sidereus Nuntius* of 1610 had been a messenger from the newly revealed heavens. Hooke says of his instrument that 'the power of considering, comparing, altering, assisting, and improving' the works of nature can be 'so far advanced by the helps of Arts and Experience, as to make some men excel others in their Observations and Deductions, almost as much as they do the Beasts.' He was perforce primarily a physical experimenter, and to biological observation he gave little more than two hurried years, 1663 and 1664. His truly extraordinary discoveries made in that short time are set out in this book, especially in its beautiful figures. A few of its figures were, perhaps, drawn by his friend, Christopher Wren (1632–1723), who, we may note, was the exact contemporary of the most industrious of all the great microscopists, Antoni van Leeuwenhoek (1632–1723).

Of Hooke's positive biological contributions the best known is his introduction of the word 'cell'. In a thin section of a piece of cork he observed a series of 'pores'. 'I told several lines of these pores, and found that there were usually about threescore of these small Cells placed end-ways in the eighteenth part of an Inch' (figure 2). He could, of course, have had no idea of the nature of a 'cell' in the modern sense, and he uses that word as equivalent to the walls of a small chamber. Nevertheless, one of his figures displays the outlines of living cells on the surface of a nettle leaf (figure 4), and he gives a good account of the stinging apparatus. In a moss also he describes and figures the cell outlines in the leaves and stem (figure 5D).

'Moss has a root with small strings or suckers out of which springs the body, which is fluted with small creases which run parallel to the whole stem; on the sides of this are thick set a multitude



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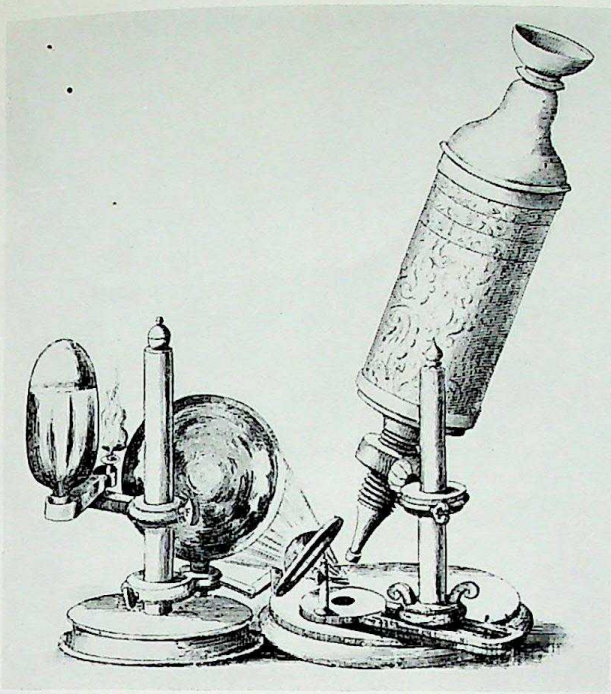

FIGURE 1 – *Hooke's microscope. Alone among the classical microscopists, he habitually used the compound instrument. The cylindrical tube, 6 or 7 inches long, could be lengthened by four draw-tubes. The eye-lens was plano-convex and rested on the top of the cylinder. The objective was double convex, of very short focal length, and had a pinhole diaphragm. For certain purposes he introduced a third glass between the two. The cup-like structure above the cylinder merely kept the eye at the correct distance from the eye-lens. The picturesque illuminating apparatus can hardly have been very efficient. (All illustrations, except figure 10, are from Hooke's* Micrographia, *London,* 1665.)

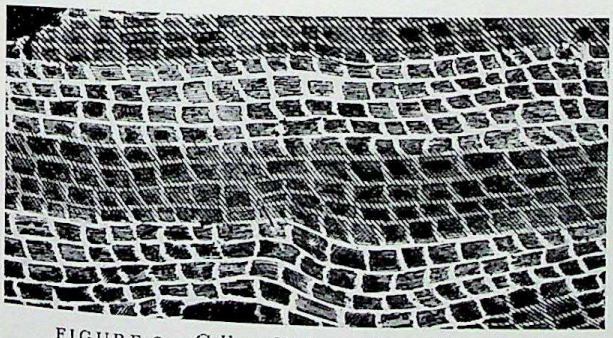

FIGURE 2 – *Cell walls in a thin section of cork.*

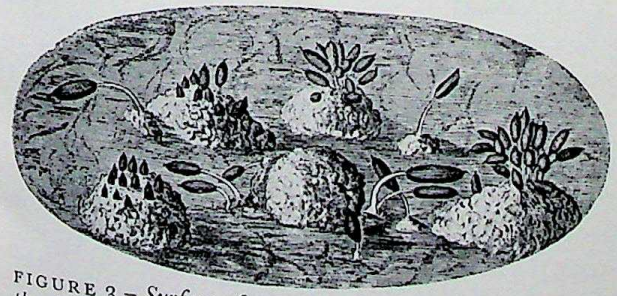

FIGURE 3 – *Surface of a rose-leaf infected with a mould of the Ascomycetes type. Stages in the emergence of the asci are well seen.*

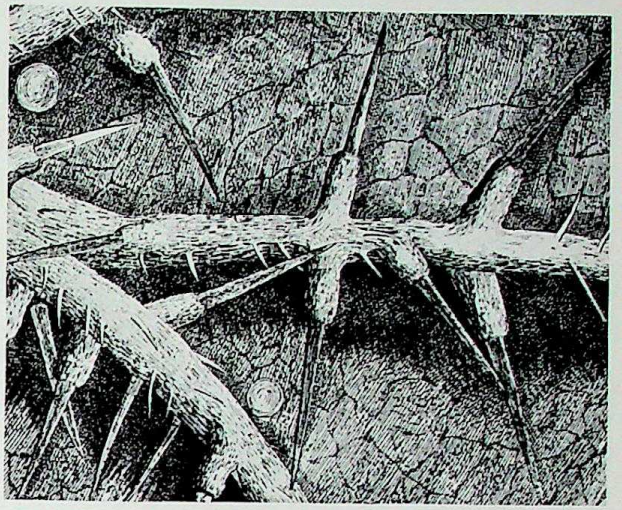

FIGURE 4 – *Part of the underside of a stinging-nettle leaf. Small simple bristles are distinguished from the larger stinging-hairs with bulb-like cellular bases. Outlines of the epidermal cells are seen and nuclei of some are perhaps vaguely indicated.*

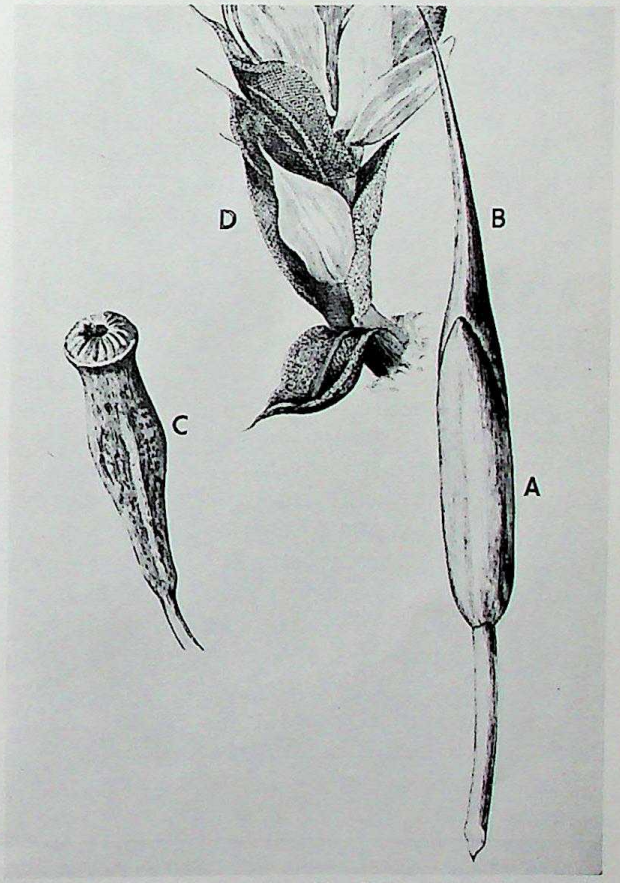


FIGURE 5 – *Moss-plant (possibly* Polytrichum*). On the surface of some leaves the cells' outlines are well seen. (B) Seta, bearing capsule with calyptra in place. (C) The calyptra has been shed and the operculum is displayed.*



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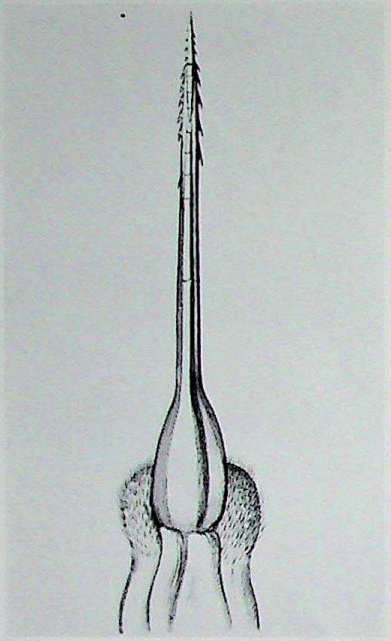

FIGURE 6 – *Bee's sting with poison-bulb at base. The director and the two barbed piercers are recognizable.*

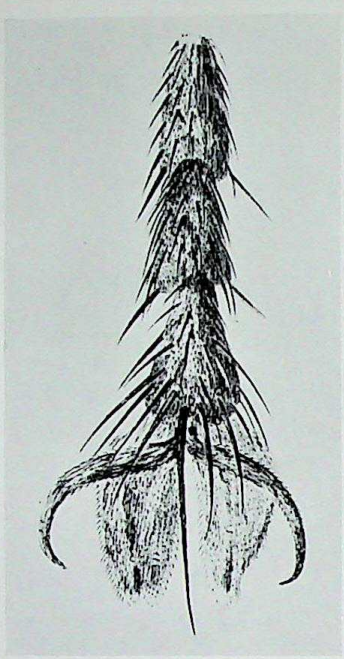

FIGURE 7 – *'Tarsus' of house-fly expressing well the hairs on the last three joints, the terminal claws, and the two pads with their minute hairs.*

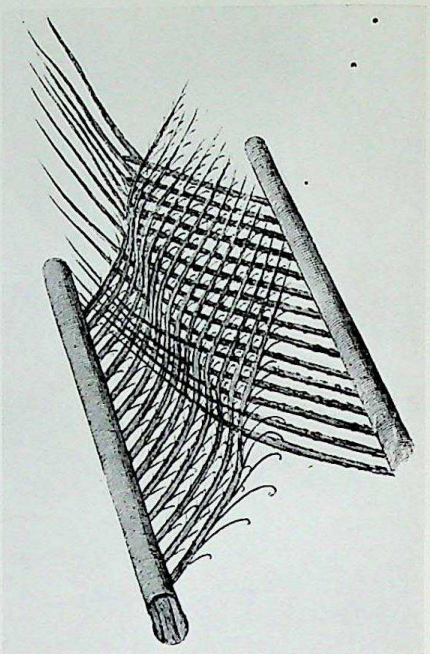

FIGURE 8 – *Elements of a goose's feather, showing minute hooks on one barbule interlocking with knobs on the other.*

of fair, well-shap'd leaves all the surface of each side of which is curiously cover'd with a multitude of little oblong transparent bodies. [These cells are shown clearly in figure 5D.] From the top of the leaves there shoots a small transparent hair or thorn [figure 5A], on which grows a large seed case [capsule], covered with a thin skin [calyptra], terminated in a long thorny top [figure 5B], which, by degrees, cleaves and at length falls off and leaves the seed case to ripen. This before the seed is ripe, appears like a flat barr'd button [operculum]. As it ripens the button grows bigger, and a hole appears in the middle of it [figure 5C].'[1]

Very striking are his observations on moulds. One kind (doubtless a *Mucor*) he describes as growing on the old damp leather of books. Another kind, one of the Ascomycetes, he saw arising on the underside of rose-leaves in autumn. Of this latter he figures the development of the spore-bearing filaments (figure 3).

Among Hooke's figures taken from the animal kingdom is one showing the structure of the bee's sting, which is better drawn than described (figure 6), and one of the foot of the fly, superbly represented (figure 7). Both of these were to become classical objects of microscopical study. His representation of the structure of a feather (figure 8) was not improved upon until the later part of the nineteenth century. His most conspicuous figures are those in the enormous plates of the louse and the flea. The latter is some 16 inches long (figure 9) and evidently suggested the curious drawing 'The Ghost of a Flea' by the artist William Blake (1759–1829) 150 years later (figure 10).

The acuteness of Hooke as an observer is peculiarly well illustrated by his treatment of the compound eyes of insects. These organs consist of aggregates of large, and often immense, numbers of elements, every one of which is provided with its own lens and nervous apparatus. Each element is capable of yielding a picture of an object from an angle slightly different from that of its neighbours. How all these pictures can be fused into one—if indeed they are fused—and how the insect can react to the result, is a current problem of animal psychology. Hooke's genius is marked by the rapidity and assurance with which he instantly seizes on such problems.

'I took a grey Drone-Fly [here a dragon-fly] that had a large head and, cutting it off, I fixed it with the forepart or face upwards upon my Object Plate [figure 11]. I found this Fly to have the biggest clusters of eyes in proportion to his head of

[1] For the sake of clarity and conciseness this passage from the *Micrographia* and those which follow have been abbreviated and the spelling and punctuation slightly modernized. They should not therefore be taken as verbatim.



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any small kind of Fly that I have yet seen. The greatest part of the head was nothing else but two large and protuberant bunches. The surface of each of these was shaped into a multitude of small Hemispheres, ranged over the whole surface in very lovely rows. I was assured of this by the regularly reflected Image of Objects which I moved to and fro between the head and the light, and by examining the Cornea or outward skin after I had stript it off, and by looking both upon the inside and against the light. Every one of these Hemispheres reflects as exact and perfect an Image of any Object from the surface as a small Ball of Quick-Silver of that bigness would do. In each of these Hemispheres, I have been able to discover a Landscape of those things which lay before my window, as I could also the parts of my window [figure 14], and my hand and fingers, if I held it between Window and Object.'

One of Hooke's best connected pieces of biological observation is on a common gnat (figure 12). During its life this creature goes through certain complete changes, or metamorphoses, which are now made familiar to most schoolchildren in the course of their nature study. These stages Hooke was the first to picture exactly.

''Tis a creature [the aquatic larva of a Culicine gnat], that wholly differs in shape from any I ever observed; nor is its motion less strange. It has a large head in proportion to its body [figure 13]. It has two horns, almost like the horns of an Oxe inverted, and with tufts of bristles at the top. These horns could move easily, this or that way, and might, perchance, be nostrils. [They are, in fact, the antennae, by the incessant movement of which the animal feeds on minute organisms in the water.] It has a pretty large mouth, which seem'd much like those of Crabs and Lobsters [i.e. with laterally movable jaws] by which I have often observ'd them to feed.

'I could perceive, through the transparent shell, several motions in the head, thorax, and belly, very distinctly, of differing kinds which shew of how great benefit the use of a *Microscope* may be for discovery of Nature's course in Animal bodies. By it we have the opportunity of observing her

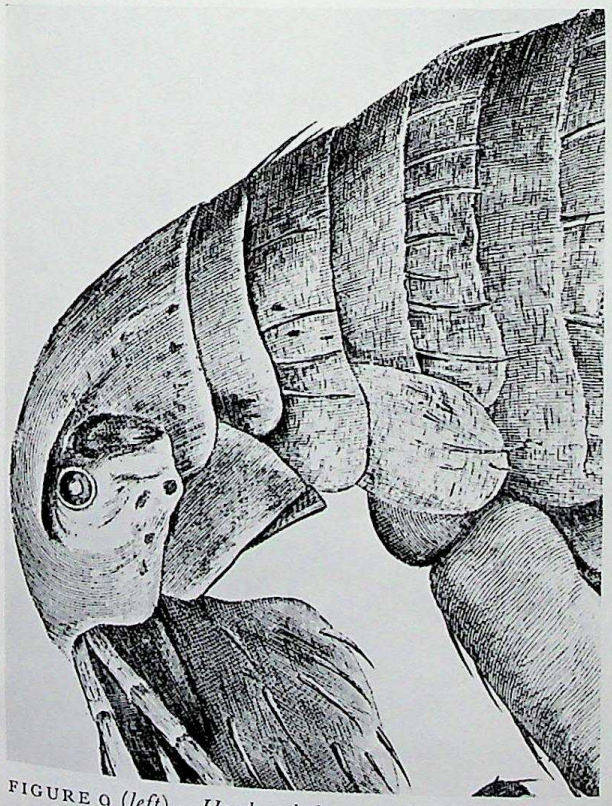

FIGURE 9 (*left*) – *Head and thorax of flea.* (*Original size as drawn by Hooke, but reversed for comparison with figure* 10.)

FIGURE 10 (*right*) – *'Ghost of a Flea,' from a drawing by the artist William Blake* (1757–1827). *It is clearly influenced by Hooke's drawing. The first joint of the forelimb is the lower jaw of the ghost. The pro-, meso-, and meta-thorax of the animal are the plaques on the neck of the ghost. The bristles on the pro-thorax of the animal are the curious strands of hair of the ghost. Other resemblances will be easily traced.* (*Reproduced by courtesy of the Trustees of the Tate Gallery, London.*)


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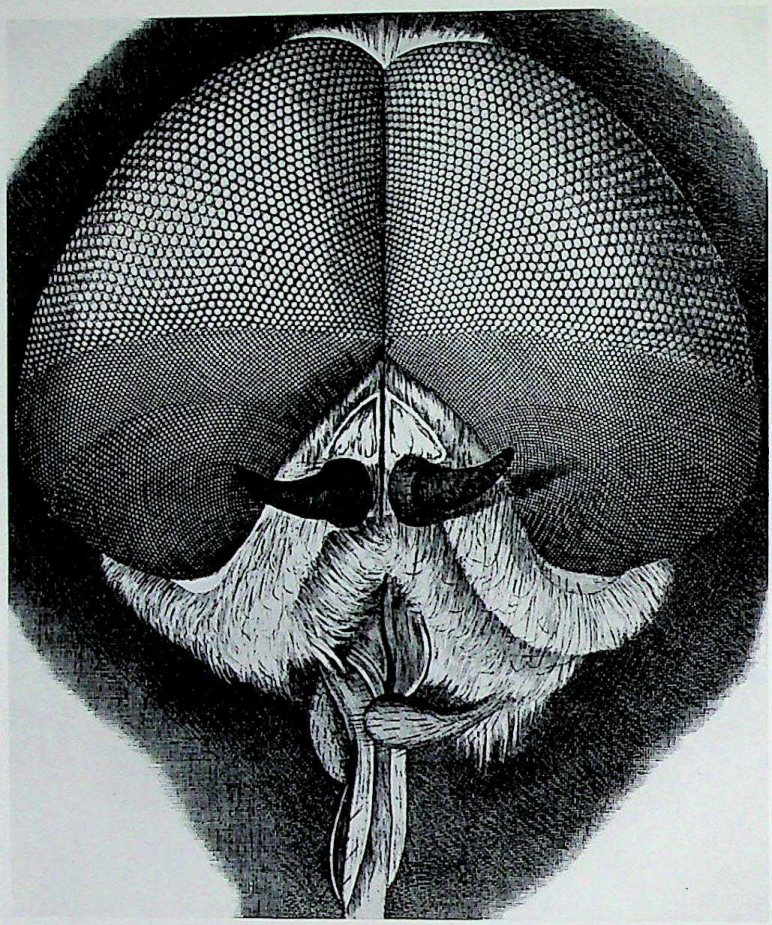

FIGURE 11 – *Head of the 'grey Drone-fly', i.e. a dragon-fly, an unidentified species. Hooke estimated* 14 000 *'hemispheres' in it.*

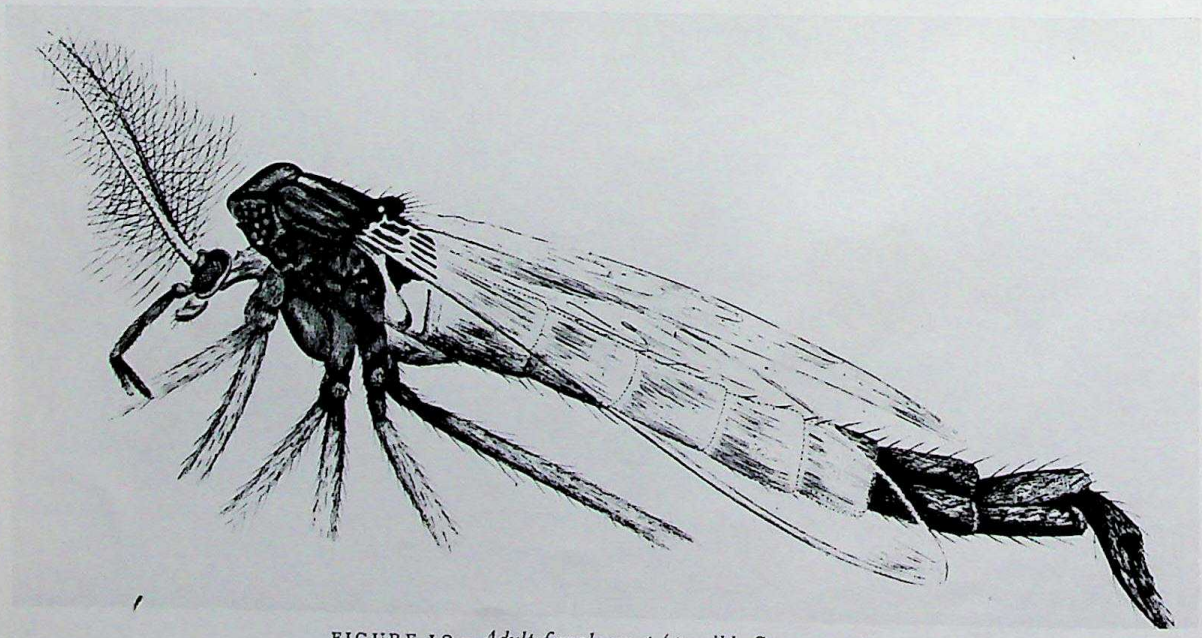

FIGURE 12 – *Adult female gnat (possibly* Stegomya).



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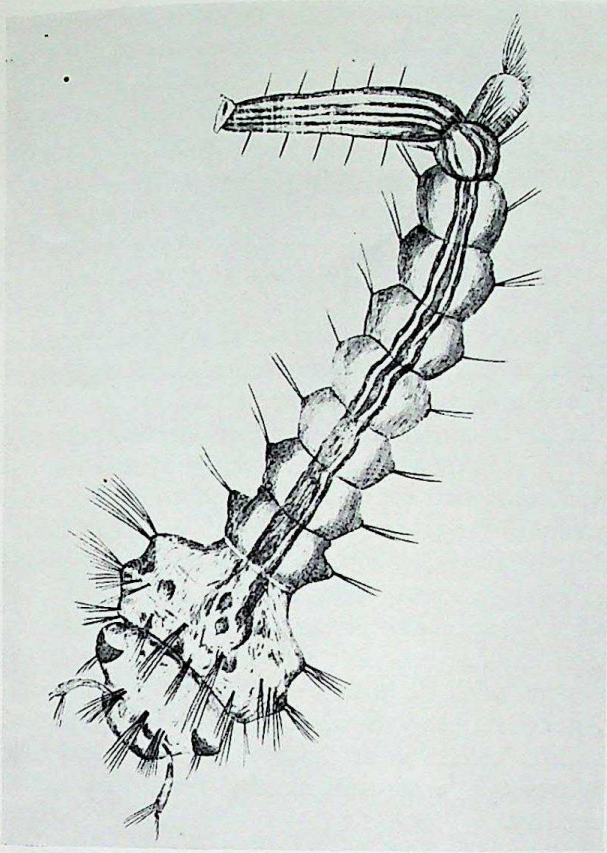

FIGURE 13 – *Larva of gnat.*

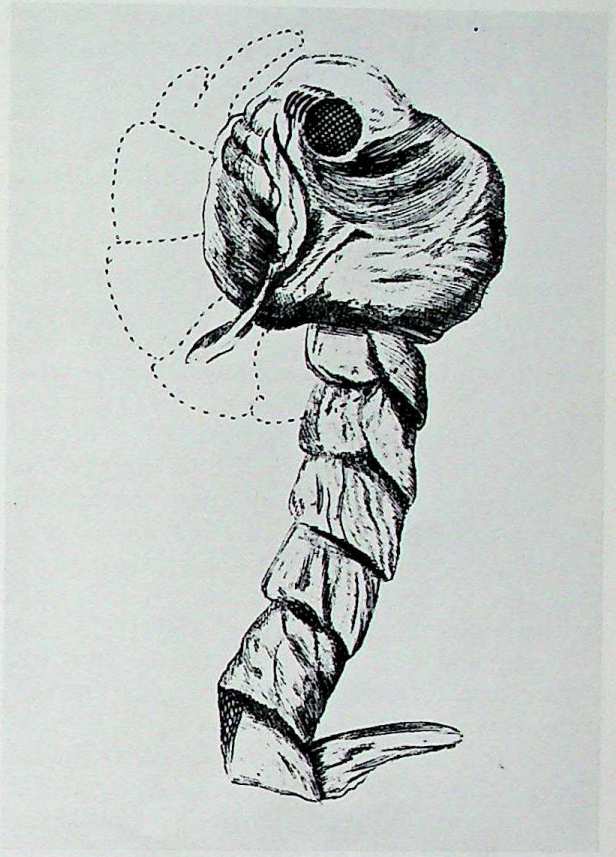

FIGURE 15 – *Pupa of gnat. Hooke has indicated by dotted lines the position of the abdomen when the animal sinks.*

through these pellucid teguments of Insects, acting according to her usual course and way, undisturbed, whereas, when we endeavour to pry into her secrets by breaking open the doors upon her, and dissecting and mangling creatures whil'st there is life yet within them, we find her indeed at work, but put into such disorder by the violence offer'd. How differing a thing we should find, if we could, as we can with a *Microscope*, quietly peep in at the windows, without frighting her out of her usual byas.

FIGURE 14 – *Part of the surface of the eye of a house-fly stripped off. It contains 19 'hemispheres'. In each is seen the reflection of the two windows of Hooke's workroom.*

'The form of the whole creature may be plainly enough perceiv'd by the *Scheme* [figure 13], the hinder part or belly consisting of eight jointed parts, from the midst of each of which, on either side, issued three or four small bristles or hairs. The tail was divided into two parts of very differing make; one having many tufts of bristles, which seem'd to serve both for the finns and tail, for the Oars and Rudder, of this little creature, wherewith it was able, by frisking and bending its body nimbly to and fro, to move himself any whither, and to skull and steer himself as he pleas'd. The other seem'd to be the ninth division of his belly, and had many single bristles on either side. [This is the respiratory siphon, the end of which when at rest is at the surface.] From the end of it, through the whole belly, there was a kind of Gut of a darker colour. The *Thorax* or chest, was thick and short, and pretty transparent, for through it I could see the heart to beat, and several other kind of motions. It was adorn'd up and down with several



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tufts of bristles. The head was likewise bestuck with several of those tufts. It was broad and short, had two black eyes and two small horns.

'Both its motion and rest is very strange and pleasant. Where it ceases from moving its body, the tail, lighter than the rest and a little lighter than the water it swims in, presently buoys it up to the top of the water, where it hangs suspended with the head downward like our Antipodes. If they do, by a frisk, get below that superficies, they presently ascend again unto it. The hanging of these in this posture, put me in mind of a certain creature I have seen in London, brought out of America, which would suspend itself by the tail, head downwards, and was said to sleep in that posture, with the young in a Purse, provided by Nature for the production, nutrition and preservation of her young ones.' [This was an opossum, a marsupial creature then on show in London, but not described scientifically until 1698.]

Hooke now relates the change of the larva into the still aquatic pupa, and the emergence from the pupa of the perfect winged insect.

'But that which was most observable in this [insect] was its Metamorphosis or change. This made me more diligently to watch if I could find them at the time of their transformation. Not long after, I observ'd several changed into an unusual shape, wholly differing from that they were of before, their head and body being grown much bigger and deeper and their belly, or hinder part smaller, and coyl'd about this great body. [They are now pupae (figure 15)]. The head and [respiratory] horns now swam uppermost, and the whole body seem'd much lighter; for when by my frighting of it, it would, by striking out of its tail, sink towards the bottom, the body would more swiftly re-ascend than when it was in its former shape.

'I still marked its progress and found it to grow bigger and bigger, Nature accoutring it for the lighter Element, of which it was now going to be an inhabitant; for, by observing one of these with my Microscope, I found the eyes to be altogether differing from what they seem'd before, appearing now all over knobbs, like the eyes of Gnats. At length, I saw part of this creature to swim above, and part beneath the surface, below which it would quickly plunge, if I by any means frighted it, and presently re-ascend. After a little I found that the head and body of a Gnat began to appear and stand clear above the surface. By degrees it drew out its leggs, first the two formost, then the others, at length its whole body, perfect and entire, out of the hulk (which it left in the water), standing on its leggs upon the top of the water. By degrees it began to move, and after flew about the Glass a perfect Gnat [figure 12].'

The appearance of *Micrographia* was the signal for a burst of microscopic research. In Italy Marcello Malpighi (1628–84) had already begun his microscopic explorations, and now he became more active. In England Nehemiah Grew (1641–1712) took up Hooke's investigations on plants, and his figures became standard for a century and a half. In Holland two micrographic geniuses, Jan Swammerdam (1637–80) and Antoni van Leeuwenhoek (1632–1723), immensely extended knowledge of the microscopic world. None of these had Hooke's imaginative insight or literary skill, and, what is specially remarkable, none of the five classical microscopists was in intimate scientific contact with the others or had significant pupils. After them follows again a relatively barren period, seldom broken until the optical properties of the microscope were improved in the nineteenth century.

Considering his numerous other occupations, the pioneer character of his observations, and that he gave but two years to biological work, the achievement of Hooke is perhaps the most noteworthy of that of all the classical microscopists. Not the least of his excellences is that his discoveries were set forth in a clear and attractive fashion which still gives pleasure as literature. Hooke was not only one of the most skilled and ingenious technicians that this country has produced, not only a scientific theorist of a high order, but a first-class observing naturalist and a master of the English language. Such a variety of talents has very seldom been assembled in one person.

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The magnification used by Hooke nowhere exceeded 150 diameters, and varies from figure to figure. Moreover, some of his originals have been somewhat reduced to fit our pages, so that it is difficult to state an exact degree of magnification for each figure. As examples, however, it may be mentioned that in *Micrographia* the magnification of the feather (figure 8) is about 124 diameters, of the flea (figure 9) about 120 diameters, and of the Ascomycetes (figure 3) about 56 diameters. We are indebted to Miss Margaret E. Rowbottom, of the Wellcome Historical Medical Museum, for these estimates.



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# The twelve whites

E. N. WILLMER

The sensation that we call white—necessarily subjective and difficult to define precisely—can be produced by irradiating the eye with a mixture of all visible wave-lengths in proportions corresponding to, for example, that of the light of the north sky. There are, however, many other circumstances in which the sensation of white can arise. Moreover—a point of importance in considering the mode of action of the receptors of the retina—both eyes can simultaneously register the sensation of white while exposed to different stimuli.

Any satisfactory theory of colour vision must integrate the physical properties of light, the physiological properties of the retina and its connections with the appropriate regions of the brain, and the psychological properties of mind. In so doing, the theory must account adequately not only for the sensations of colour but for the more basic, and perhaps less spectacular, sensation of white, for this too must have its origins on the physical, physiological, and psychological planes. Moreover, white is in some ways different from colour in that the sensation of it can arise under a wide variety of conditions. The sensation of white, of colourlessness, or simply of 'light', is probably the most primitive visual sensation, and the sensations of colour almost certainly demand accessory mechanisms of one sort or another.

Any precise definition of white is almost impossible. Whiteness, like colour, is strictly subjective, synonymous with the complete absence of any sensation of hue, and like colour it depends as much on the physiological mechanisms as it does on the physical characteristics of the light. It is true that, other things being equal, the light of the cloudy north sky at noon, when reflected from a magnesium oxide surface, may be called white. A black body radiating at a colour temperature of about 5500° K may also evoke a sensation of white. Either could be arbitrarily adopted as a standard, but nevertheless both would evoke a sensation not of white but of green if the eye of the observer had been previously exposed to a bright red light for some minutes and had become 'adapted' to it. Figure 4 illustrates that a white page may in some circumstances appear to be anything but white.

Sunlight may sometimes be taken as white, but generally it appears yellowish. Under some conditions it can certainly appear white, and it is a curious phenomenon, having in all probability both a physiological and a psychological basis, that the whitest, or least saturated, surface in the field of view at any one time tends to be regarded as white until something whiter is introduced. Furthermore, surfaces known to be basically white, e.g. white paper or a white wall, are generally still called white, even when predominantly red (or indeed any other coloured light) is being reflected from them.

The various conditions under which the sensation of white can arise are, briefly, as follows.

1. Under ordinary daylight or 'photopic' conditions (i.e. when the eye is light-adapted and when colours, if present, could be fully distinguished) the sensation of white is normally produced when the eye is simultaneously irradiated with light of all wave-lengths of the visible spectrum, in amounts roughly corresponding to their distribution in the spectrum of north daylight or of a black body radiating at 5500° K. Almost any arbitrary standard could be chosen as white under conditions approximating to those described, since, under reasonably normal conditions, it could be made to evoke a colourless sensation. As mentioned above, the eye tends to adapt itself and to desaturate colours which are nearly white until one of them is regarded as being white.

White can therefore result from irradiating the eye with an appropriate mixture of all wave-lengths of the visible spectrum at once.

2. A sensation of white also results from mixing, in the correct proportions, certain pairs of lights of particular wave-lengths, the so-called complementary pairs. For example, a yellow light when mixed with the right amount of blue becomes a white (figure 1); similarly the addition of red light to the appropriate blue-green also causes the disappearance of all colour, and such mixtures of pairs of wave-lengths can be perfectly matched with whites produced by the whole spectrum as already described. It should perhaps be emphasized that mixture of blue and yellow pigments



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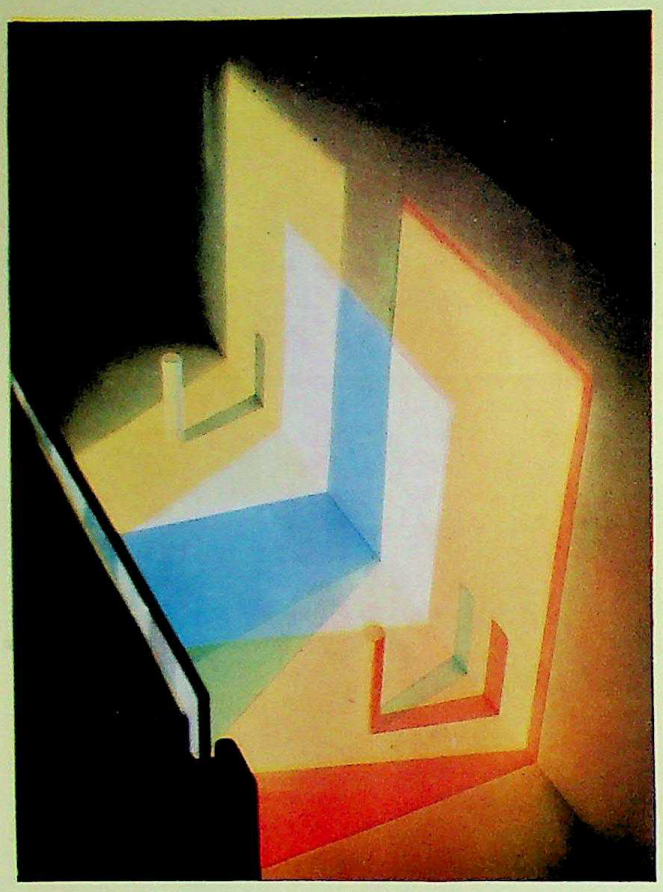

FIGURE 1 – *The white on the left is a mixture of blue with monochromatic yellow. The white on the right is a mixture of blue with yellow made by mixing red and green.*

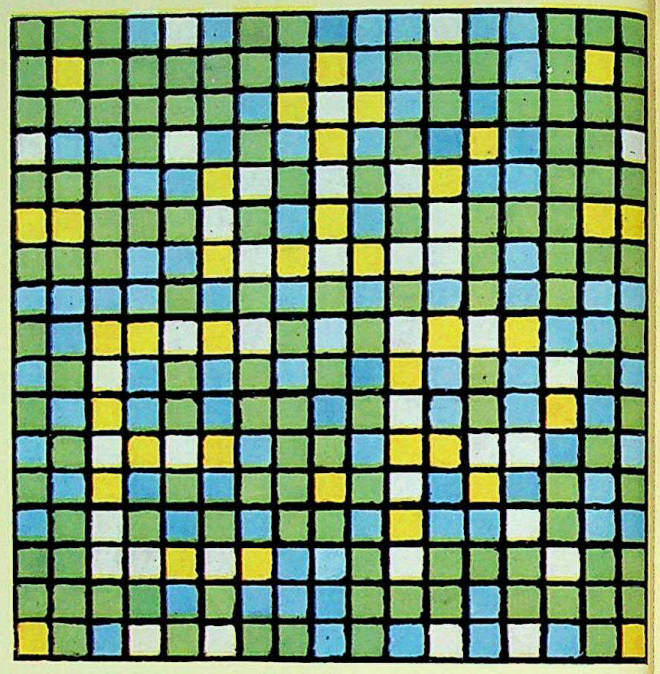

FIGURE 2 – *If you cannot see a pattern on this figure, examin it from a distance of more than 4 metres. (This figure should b examined in daylight.)*

FIGURE 3 (*right*) – *Fixate the green spot from a d of 3 or 4 metres, and observe what happens to the and white spots. Compare them in colour with the whi*

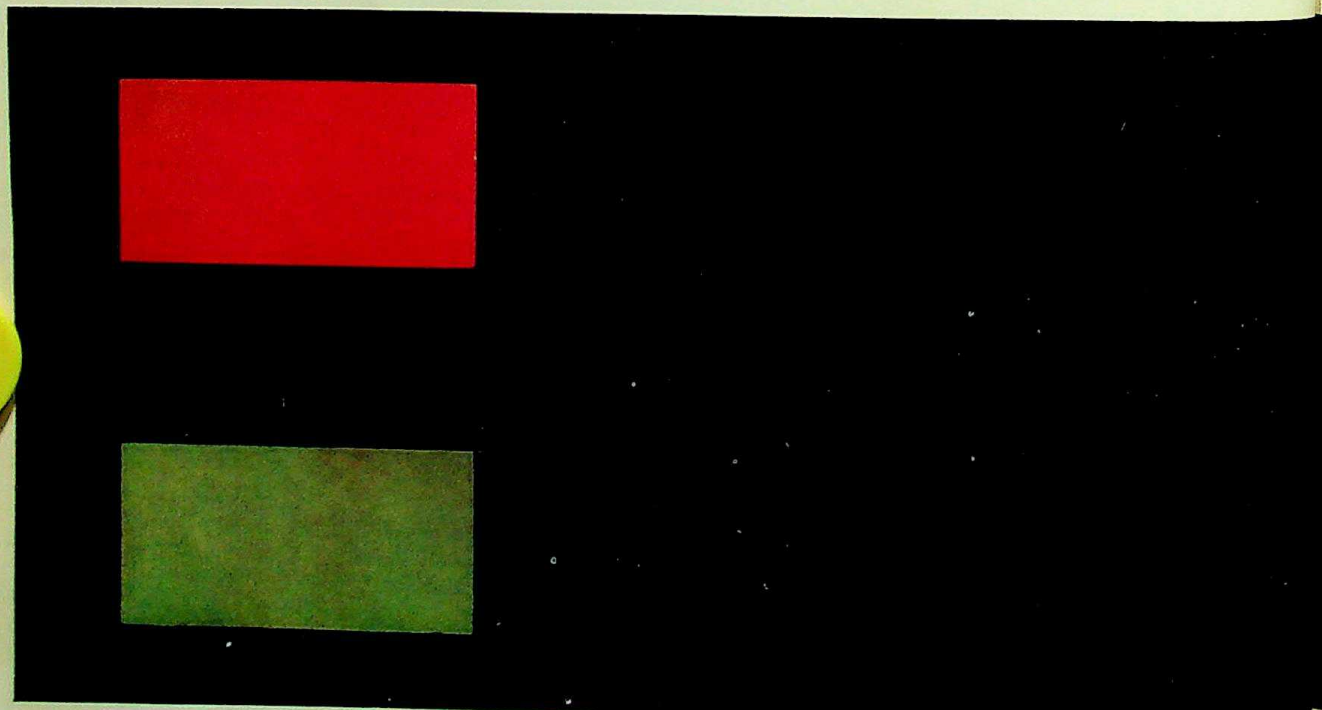

FIGURE 7 – *Hold the page very close to the face in such a position that the right eye looks directly at the white spot. Bring the right-hand page slowly forward from a position behind the field of view of the right eye until the coloured patches slowly*

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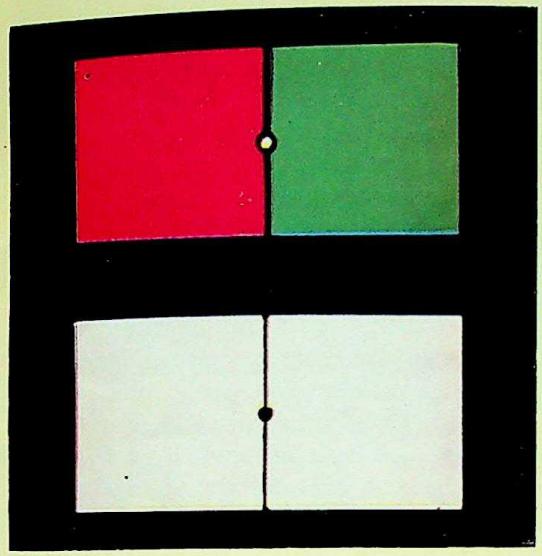


FIGURE 4 – *Fixate the white point marked between the red and green fields for 20 seconds or more. Rapidly transfer the gaze to the black spot in the lower half of the diagram and observe the 'white' fields.*

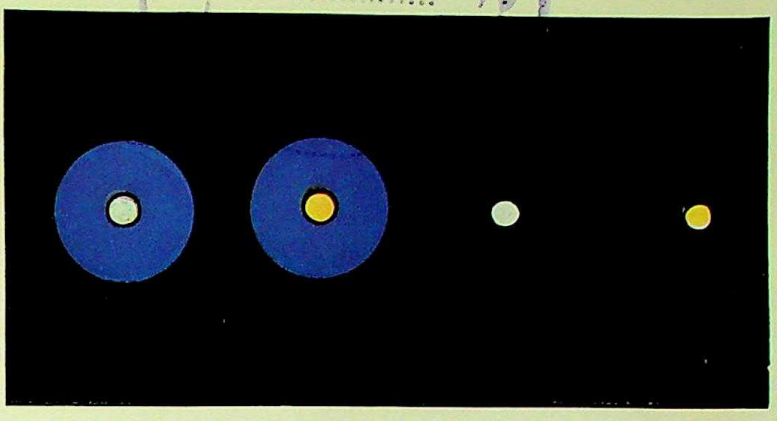
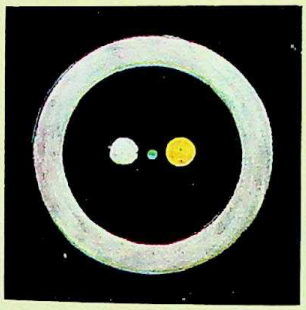


FIGURE 5 – *Examine these spots from a distance of about 4 metres. Fixate each in turn, avoiding eye movements, and arrange in order of 'whiteness.'*



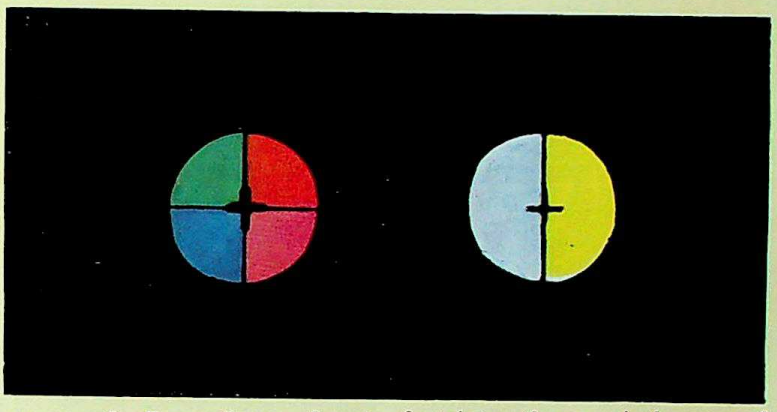
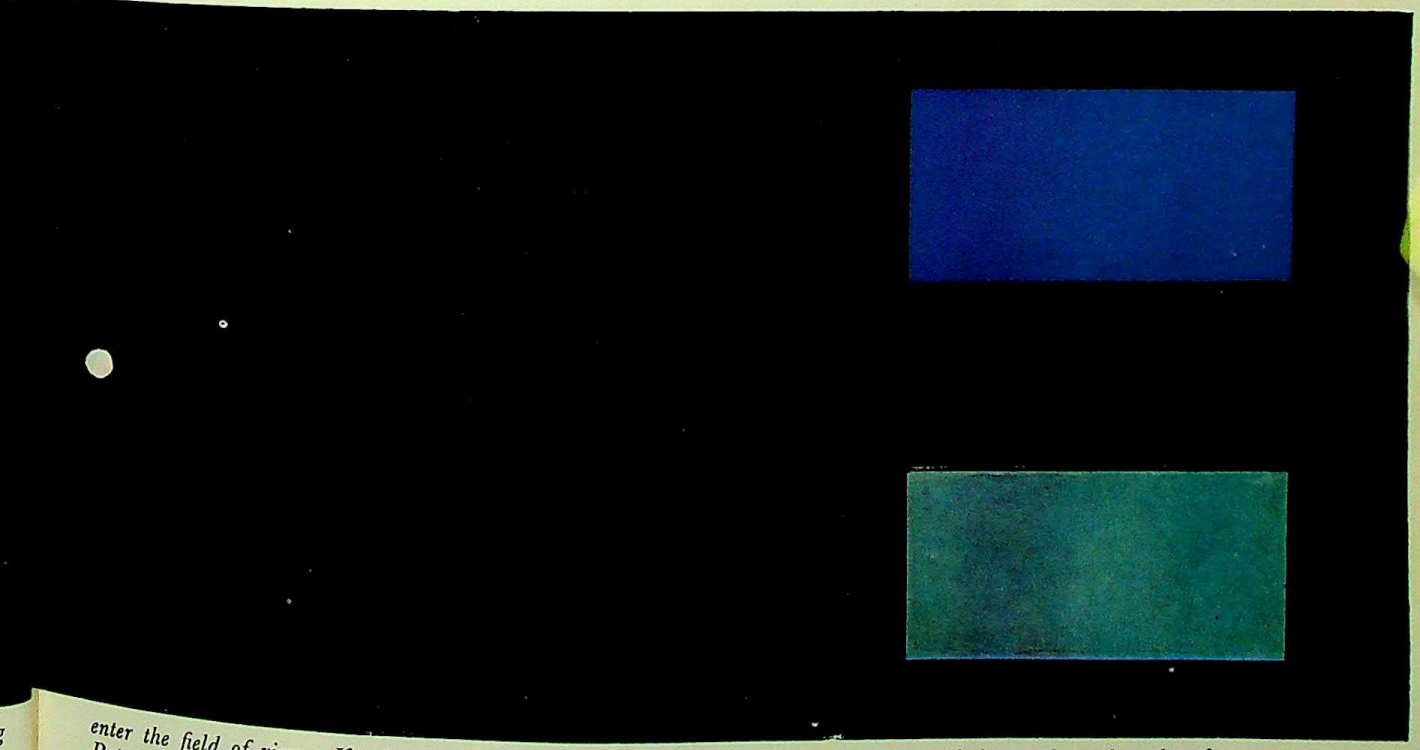


FIGURE 6 – *From a distance of 4 metres fixate in turn the crosses in the centres of the two circular fields with one eye; avoid eye movements. The results demonstrate the effects of foveal tritanopia. (This figure is best examined in daylight.)*



*enter the field of view. Keeping the eye directed at the white spot, note the colour of the patches when they first appear. Repeat with the left-hand page, using the left eye. Particularly note the appearance of the upper patch on the left-hand page.*

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does not lead to the same result, since the effect of such a mixture is subtractive while that of lights is additive.

White can therefore result from the mixture of two or more isolated wave-bands, and the whole spectrum is not necessary.

3. It is a common experience that in the hours of twilight blue flowers apparently lose their colour and become white, while red flowers appear black. An observer in a dark room, examining a visual field illuminated by blue or blue-green light and gradually reducing the intensity of the light, notices that at a certain stage, depending on the wave-length, the light becomes colourless. Indeed, below a certain level of luminance (brightness) any light, with the possible exception of the far red—it does not matter whether it is monochromatic or covers the whole spectrum—will thus lose all colour. Moreover, if a light which appears white to the observer under photopic conditions is gradually reduced in luminance until it is only just visible with the fully dark-adapted eye (i.e. under 'scotopic' conditions), the sensation which it evokes remains colourless, in the absence of disturbing factors, until it fades away through grey to black. There is thus a smooth transition from photopic white to scotopic white, even though the one may be produced by the whole spectrum and the other by a single limited wave-band.

White can therefore result from light of any or every wave-band (except possibly extreme red), provided that the intensity is below a certain level and that the observer is dark-adapted.

4. All colours, when made sufficiently bright, tend to lose their colour; they desaturate, and eventually appear white. This naturally happens most easily with the originally less saturated yellows and greens, and least easily with the highly saturated violet and red. Colours thus not only desaturate into grey or black at the lower levels of luminance, but they desaturate towards white at high luminances: this is not necessarily the result of a wider spectral band reaching the eye at high luminances, though this may sometimes contribute.

White may thus result from the desaturation of colours at high luminance.

5. The pattern on figure 2, when seen at close quarters, is probably meaningless to most people, but when viewed from a distance (3–4 metres) its significance is apparent. Similarly, the yellow spot which is surrounded by blue in figure 5 will, when viewed from about 4 metres, appear to be completely colourless. If firmly fixated, it may appear to be even whiter than the genuinely white spot on a black ground when that is similarly fixated. In fact, when each is examined in turn, the spots in this figure can be arranged in order of increasing whiteness to the left. The cause of these anomalies is uncertain. They may result partly from simultaneous contrast; they may be caused by the spreading and overlapping of images on the retina; or they may be of the same nature as the effects described in the next section.

White thus results when a small yellow field is surrounded by, or placed next to, a small blue field.

6. Study of the effects of steady fixation on the appearance of colours has shown that the central fovea (the point of most distinct form-vision in the eye) makes certain definite confusions of colour; these help to explain the appearance of the pattern which emerges from figure 2 when it is viewed from a distance, and which cause the quartered circular field of figure 6 to appear as a simple bisected field when its image falls on the fovea. A point in the yellow region of the spectrum (generally about 5700 A) can then be satisfactorily matched with white. Steady fixation of the green spot in figure 3, when the figure is viewed from a distance of 3 or 4 metres, will remove all difference of hue from the two adjacent spots, and both will appear colourless.

A sensation of white thus arises at the neutral point (approximately 5700 A) in the spectrum when vision is confined to the central fovea by means of steady direct fixation of the eye.

7. A similar phenomenon occurs with extreme peripheral vision, under photopic conditions, when a green light (about 5000 A) is flashed on the eye from a direction making an angle of more than 70° with the direction of gaze. All wave-lengths shorter than about 5000 A appear bluish under these conditions, while all longer wave-lengths appear yellowish (figure 7).

A colourless sensation is therefore aroused under photopic conditions by a narrow wave-band in the spectrum, at about 5000 A, when this illuminates the far periphery of the retina.

8. Under conditions of poor illumination the above wave-band extends along the spectrum in both directions and eventually the long wave-lengths alone seem coloured; incidentally, they now appear as red, rather than yellowish as under photopic conditions. The whole of the rest of the spectrum gives rise to a colourless sensation, and this effect, though it occurs at a higher brightness level, is probably comparable with that described previously in section 3.



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Under conditions of poor illumination, though not necessarily strictly scotopic conditions, all wave-bands of the spectrum from violet to orange are seen as white by the extreme peripheral retina.

9. People with abnormal colour vision who can match all the spectral colours by means of two primaries instead of three are called dichromats. They fall into three main groups: (1) protanopes, often incorrectly called red-blind; (2) deuteranopes, often incorrectly called green-blind; and (3) tritanopes, often incorrectly called blue-blind. All such subjects have a neutral point in the spectrum which they can match with white. These neutral points occur at different points according to the defect. The average values are 4930 A for protanopes, 4970 A for deuteranopes, and 5680 A for tritanopes. The last is in the same region of the spectrum as the neutral point for the normal central fovea, and in fact the central fovea is correctly described as being tritanopic.

For dichromatic subjects there is one spectral region causing the same sensation as does the whole spectrum when combined as white, or as do any or all wave-lengths in scotopic vision.

10. When the vision of two of these groups of dichromats, the protanopes and the deuteranopes, is confined to the central fovea, as it is when such a figure as figure 6 is seen from about 3 or 4 metres away by direct and steady fixation, another effect is noted. Both circles appear to such subjects as a uniform grey, or they may appear as grey but with different degrees of brightness in the different quadrants according to the type of defect of vision present. Such subjects can, in fact, match any wave-length with white when their vision is strictly confined to the central fovea and eye movements are avoided. The sensation which they receive under such conditions is described as being identical with the white of their scotopic vision, which is presumably the same as that seen by the normal person. Tritanopes do not show this foveal monochromacy.

Protanopes and deuteranopes, in the absence of any comparison fields, see all parts of the spectrum as colourless in the central fovea and can match all wave-lengths with white.

11. When the vision of the normal person is confined to the central fovea and the eye has been previously 'adapted' to a bright red light, a large part of the spectrum, from about 5200 A (green) to the red end, becomes uniform in hue and extremely desaturated, if not actually white. Similar effects, i.e. extreme desaturation of the spectrum from the blue end to about 6400 A, follow adaptation to bright blue or blue-green. With the whole eye, very similar results are obtained if it is first adapted to violet and then to either red or blue-green. Under these conditions, large parts of the spectrum become highly desaturated, and it becomes difficult to name the hue perceived. Although superficially similar, these conditions are not identical with those described in section 4.

Adaptation of the eye to certain bright lights of restricted wave-bands is followed by a period during which large spectral regions give rise only to colourless or very desaturated sensations.

12. There are certain rare colour-blind subjects, the monochromats, who see no colour whatsoever in the spectrum; their sensation of light is, under all conditions, comparable with their scotopic sensation and may therefore be presumed to be the same as the colourless sensation, or white, of the normal person. On the basis of their relative sensitivities to the different parts of the spectrum there appear to be two, or perhaps three, classes of such subjects, and they all behave similarly.

White may thus arise under a variety of conditions. Even in the normal subject it is possible to match binocularly a normal photopic white in one eye with a scotopic white in the other, or with the white perceived when a yellow spot falls on the central fovea only, or again with an orange spot whose colour has been modified by previous adaptation to violet and red. It is pertinent, therefore, to inquire what the various photoreceptor cells are doing under all these varied conditions. Clearly, they cannot always be doing the same thing, and this is a thought which, if extended, might be found to be somewhat disturbing to the commonly accepted view that if two visual fields match, then the corresponding receptors in the retina are being equally stimulated by the two fields. In the case of white they certainly need not be. When figure 3 is examined by direct fixation of the central green spot from a distance of about 3 or 4 metres the white ring will be seen to surround two white spots. These two spots are falling on the dichromatic foveal centre, while the ring falls on the trichromatic periphery. Moreover, if the illumination is reduced there will come a time when, however they are observed, all the spots appear white or grey and only monochromatic ('twilight') vision is being used. The sensation of white can thus arise as the result of appropriate stimulation of monochromatic, dichromatic, or trichromatic mechanisms, and in the perception of white the eye does not appreciate the change-over from one system to another.



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# Storms in the ionosphere

SIR EDWARD APPLETON

For more than a quarter of a century the terrestrial ionosphere has been regularly explored by vertical radio-sounding. In addition to the regular features in its behaviour which have been thus revealed, world-wide disturbances in its upper structure have been observed to occur at times of magnetic storms. Such ionospheric storms are responsible for many of the interruptions which occur in short-wave communications over global distances.

The ionosphere is a shell of ionized air surrounding the earth at high atmospheric levels. Its exploration and theoretical study have a practical as well as a scientific importance, for we know that it is due to the reflective power of the ionosphere that short radio waves can be successfully transmitted over great distances. Moreover, the ionosphere itself constitutes a laboratory in which the radiophysicist can study the atomic processes of ionization and electronic recombination under low-pressure conditions not realizable at ground level. The ionosphere was first discovered by means of radio reflection experiments in 1924. Ionospheric exploration by radio probing has since been both developed in precision and extended in world coverage; in recent years such observations have been supplemented by rocket soundings. The ionosphere is stratified in various layers, and the radiophysicist has studied the regular ionic variations in these layers during the course of the day, during the seasons, and during the sunspot cycle of about eleven years. This has been done during the last quarter of a century, and, as a result, the subject of ionospheric forecasting has been developed. From a knowledge of past ionospheric events, together with an extrapolation related to the trend of the sunspot cycle, it is possible to estimate the kind of ionospheric conditions which are likely to obtain, say, three months ahead. From radio theory it is then possible to predict the range of wave-lengths which will be most successfully reflected by the ionosphere at any time of the day, over any length of radio circuit, and in any part of the world. All the radio wave-length planning in Britain for long-distance radio transmission, for both defence and civil services, is based on such forecasts.

The experimental radio-sounding of the ionosphere for ionospheric forecasting is almost invariably carried out by the pulse reflection method. This involves the accurate timing of the travel of the radio pulse up to the ionosphere and back. Since the pulse propagation in such a sounding is usually vertical in direction, we know that the radio waves travel into the ionosphere until they encounter a stratum where the electron density is sufficient to reduce the refractive index to zero. It is at that level that the waves are reflected. This is a simple result which follows from the laws of optics; however, the fact that electrons, rather than ions, are the effective charges in the ionosphere introduces a complicating factor into the relevant dispersion theory. Because of the influence of the earth's magnetic field, the ionosphere is a doubly refracting medium for radio waves. A radio pulse entering the ionosphere is therefore split into two components of complementary polarization, and we can speak, as in the case of the optics of uniaxial and biaxial crystals, of ordinary waves and extra-ordinary waves. In general, therefore, a single radio pulse is reflected as a doublet, because the ordinary and extra-ordinary components travel with different group velocities and are reflected at slightly different levels within an ionized layer. The conditions for reflection at vertical incidence for the ordinary wave component are expressed by

$$\mathcal{N} = \frac{\pi m}{e^2} f^2 \quad \ldots\ldots\ldots\ldots (1)$$

The corresponding relation for the extra-ordinary wave is

$$\mathcal{N} = \frac{\pi m}{e^2} (f^2 - f f_H) \quad \ldots\ldots\ldots\ldots (2)$$

Here $\mathcal{N}$ is the number of electrons, of charge $e$ and mass $m$, per unit volume, $f$ is the radio wave frequency, and $f_H$ is the gyro-frequency with which free electrons rotate round the earth's magnetic lines of force. In Britain, for example, $f_H$ is $1{\cdot}3 \times 10^6$ cycles per second. Equations (1) and (2) tell us therefore that radio pulses of, say, 4



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megacycles per second (Mc/s) would require an electron density of $2 \times 10^5$ per $cm^3$ for reflection in the case of the ordinary wave and $1{\cdot}3 \times 10^5$ per $cm^3$ in the case of the extra-ordinary wave.

In routine radio-sounding, attention is usually centred on the ordinary wave, since this is the stronger component of the magneto-ionic doublet. Equation (1) therefore applies, and we note that the ionospheric electron density necessary for reflection at vertical incidence is proportional to the square of the radio frequency employed. By running steadily through the whole gamut of radio frequencies which the ionosphere will reflect at any time, it is possible to find the relation between the equivalent height of reflection $h'$ and the frequency $f$. This $(h', f)$ relation is the basic expression in ionospheric sounding, since from it we can find the critical penetration frequency of any particular ionized layer. For such a critical frequency we are evidently concerned with maximum ionization conditions and equation (1) therefore becomes

$$N_m = \frac{\pi m}{e^2} f_c^2 \quad \ldots\ldots\ldots\ldots (3)$$

where $N_m$ represents the maximum electron density in a layer and $f_c$ the limiting frequency of penetration.

The two main layers in the ionosphere are the E and F layers; their lower boundaries are situated at heights of about 100 and 230 km respectively. In addition, there is situated, below the E layer, the D layer, which, while reflecting extremely long waves, acts mainly as an absorbing stratum for the shorter wave-lengths which must travel through it on their way to the E and F layers, where they may be reflected. Detailed observation has shown that the F layer consists of two overlapping strata, the F1 and F2 layers, which have quite different, and readily recognizable, characteristics. Generally speaking, the E and F1 layer variations are much as one would expect, assuming that, as is known to be the case, both layers are formed as a result of ionization by solar photons. The maximum ionization densities in both layers start to increase as the sun rises each morning, reach maxima very slightly after noon, and then decay as the sun sets. Also, the maximum ionization densities are greater in summer than in winter. Such regularities are not, however, paralleled in the F2 layer, which is, as has been indicated, the highest layer in the ionosphere. It is true that the F2 layer exhibits features suggesting a general solar control, in that its maximum ionization density is greater during the day than during the night, but when we examine its world morphology or its response to changing seasons, many anomalous characteristics become evident. The first F2 layer anomaly of this type to be recognized was that the maximum ionization density at noon is less in summer than in winter. To account for this anomaly we can picture the layer as being expanded in thickness, the expected ionization being present, but being spread out, for some reason, over a greater range of vertical height. This is illustrated in figure 1. The physical process is important, because it turns out to be the cause of many F2 layer anomalies.

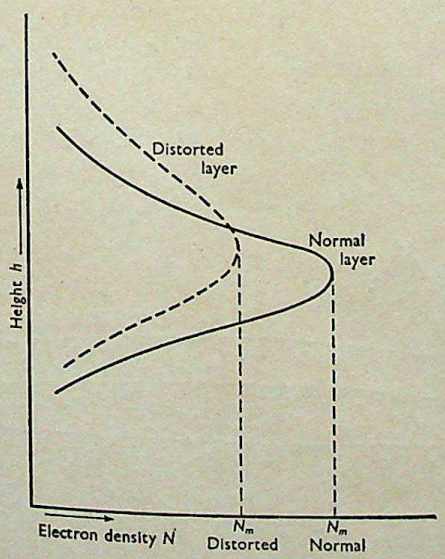


FIGURE 1 – *Illustrating how the maximum ionization density $N_m$, of an ionized layer, can be reduced as a result of vertical differential expansion.*

So far we have been concerned with the regular behaviour of the ionosphere as exhibited in the temperate latitudes, where ionospheric sounding by radio began. However, since it was well known that auroral and other disturbances occurred in the upper atmosphere, particularly in high latitudes, it was decided, some twenty years ago, to undertake ionospheric observations at a site near the northern auroral belt. A convenient occasion was the Second International Polar Year 1932–3, when a British radio expedition was sent to Tromsö, in northern Norway, under the auspices of the Royal Society and of the Department of Scientific and Industrial Research. The British party worked at Tromsö for more than a year, and were able to lay the foundations of our knowledge of ionospheric conditions in high latitudes. It was quickly found that ionospheric disturbances accompanied auroral and magnetic storm



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manifestations. It was found that during such conditions D layer absorption was intense, resulting sometimes in complete absence of radio reflection. It was generally found that when the absorption abated the F2 layer had also been affected, the value of the maximum electron density $N_m$ having been reduced. Since, at the same time, the height of the layer had been increased, it was clear that some such upward inflation mechanism as that illustrated in figure 1 had been operative.

The results at Tromsö naturally prompted the search for ionospheric storm phenomena, associated with magnetic storms, at lower latitudes. As in so many other fields of scientific research, it was a case of knowing exactly what to look for. At temperate and equatorial latitudes there was little variation to be noted in the D, E, and F1 layers, but pronounced changes were noted in the F2 layer. Taking noon conditions first, it was found that there was a general tendency in temperate latitudes for $N_m$ to be reduced, though less markedly than at high latitudes. This applies at most seasons, midwinter being the only exception. Near the equator, however, values of $N_m$ were found to be increased during storm conditions, indicating possibly that a contraction of the F2 layer had occurred.

For many years it seemed odd that noon ionospheric storm conditions were so different in equatorial regions from those in high and temperate latitudes. In 1946, however, a further anomaly in the F2 layer was identified: it was shown that equinox noon values of $N_m$ were more nearly related to magnetic latitude than to geographical latitude. This led to a more coherent picture of F2 layer morphology, over the world as a whole, for both quiet and disturbed conditions. Particularly, it was discovered that under normal conditions there is, at noon, a belt of low values of $N_m$ centred on the magnetic equator. This is illustrated in figure 2, where the relations between $N_m$ for the E, F1, and F2 layers and geographical latitude are shown for a line of longitude (75° W) corresponding to the east of North America. It will be seen that $N_m$ for both the E and F1 layers is symmetrically related to the geographical meridian; whereas in the case of the F2 layer the curve is symmetrical relative to the magnetic equator, which, on the particular longitude concerned, lies about 11° south of the geographical equator.

Guided by the recognition of the geomagnetic control indicated in figure 2, it is possible to illustrate the effects of the same ionospheric disturbance at different sites. Using results for a number of stations, the ratio of the values of $N_m$ under disturbed and quiet conditions (i.e. $D(N_m)/Q(N_m)$) is plotted in figure 3 as a function of geomagnetic latitude. We see at once that, in the higher latitudes in both hemispheres, $D(N_m)$ is less than $Q(N_m)$, but that, over a belt centred on the magnetic equator, the storm value of $N_m$ is greater than the quiet day value. There are two further features of figure 3 to be noted. First, the belt over which $N_m$ is increased during storm conditions is a little wider than the belt of the F2 layer equatorial anomaly illustrated in figure 2. Second, the belt of increased $N_m$ values appears to extend into slightly higher latitudes in the southern hemisphere than in the northern hemisphere.

So far I have dealt with local noon values only, and yet figure 3 is derived from the results of stations of widely differing longitude, the actual times of observation differing between themselves by many hours. Such consistency as is shown among the results exhibited in figure 3 is due to the fact that an ionospheric storm is, very largely, a local-time effect, and the results for different stations during the same storm can be reconciled

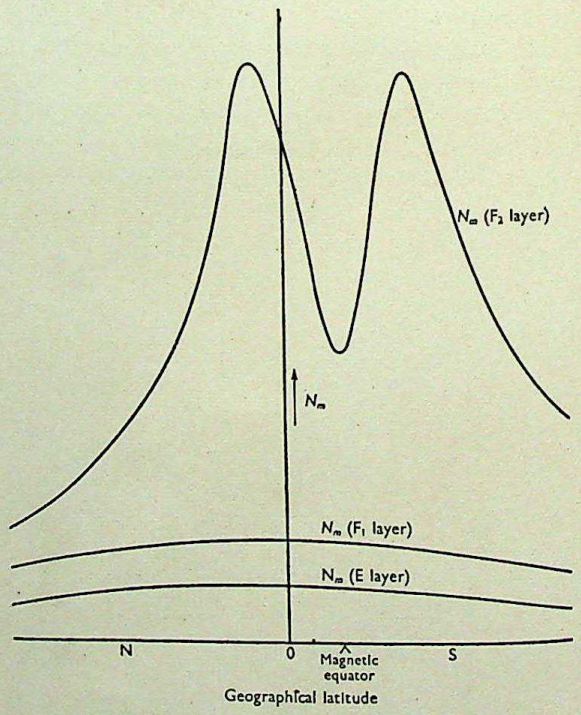


FIGURE 2 – *Showing how the maximum electron density, $N_m$, varies at noon, along a line of longitude 75° W, in the E, F1, and F2 layers. While the E and F1 layers are symmetrically developed with respect to the geographical equator, the F2 layer is subject to a geomagnetic control.*



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only if this is recognized. For medium-latitude stations the negative phase of the depression of $N_m$ below normal travels round the earth with the sun. We can thus see how, as sometimes happens, the first negative phase of an ionospheric storm may be recorded at different longitudes on different dates. Actually, of course, the complete description of an ionospheric storm is the full record of the diurnal changes in $N_m$ at all sites. These differ according to the geomagnetic latitudes of the stations, and will not be described here. However, the noon results are a fair guide to events during the day as a whole.

I now turn to consider the practical implications of these storm changes in the F2 layer, since this layer is the most important component of the ionosphere from the standpoint of radio communication. In short-wave transmission the choice of an optimum frequency is made by striking a balance between two conflicting considerations. In order to reduce D layer absorption, as high a working frequency as possible is desirable, yet it must not be so high as to pierce the F2 layer. But the higher the value of $N_m$ in the layer and the lower the level of the layer maximum, the higher is the range of frequencies reflected. We can therefore see that in high and medium latitudes where, under storm conditions, the layer is expanded and elevated as illustrated in figure 1, the maximum frequency reflected will be much less than normal. On the other hand, the storm conditions in the equatorial belt are more favourable for short-wave radio reflections than the normal, for the increase in $N_m$ is brought about by a vertical contraction of the layer, which results in the height of the layer maximum being slightly reduced.

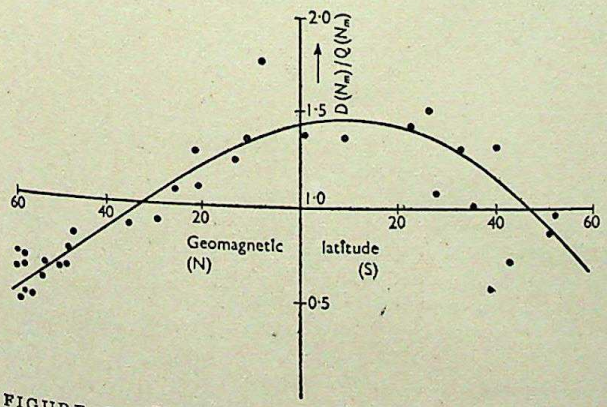


FIGURE 3 – *Showing the ratio $D(N_m)/Q(N_m)$ plotted with geomagnetic latitude. It will be seen that $N_m$ is greater on magnetically disturbed days than on magnetically quiet days at low latitudes. The reverse is the case at higher latitudes.*

Thus both factors favour the use of high radio frequencies in communication in equatorial regions under storm conditions.

These purely scientific results can be readily confirmed from actual operations on long-distance radio circuits. During ionospheric storms the route of the radio waves from England to Canada lies along a great circle which is not far from the auroral zone. At such high latitudes the large reduction in the value of $N_m$ is often accompanied by increased absorption and, when both effects are excessive, communication may be completely disrupted. On the other hand, the radio circuit to Cape Town may be, at the same time, only slightly disturbed. It is the liability of transatlantic radio circuits to periodic storm conditions that has underlined the urgency of the need for a new submarine telephone cable across the Atlantic. Meanwhile some mitigation of ionospheric storm difficulties can often be obtained by sending radio messages from England to North America by way of a relay station situated in equatorial regions.

To the general geophysical picture of auroral disturbances and magnetic storms, associated usually with the occurrence of sunspots, we can now add the phenomenon of the ionospheric storm. Auroral displays in high latitudes, however, are usually explained as due to the irruption of electrified solar particles into the earth's atmosphere along auroral belts centred round the two geomagnetic poles. Yet magnetic storm effects are of world-wide occurrence, and, as we have seen, disturbances in the ionosphere associated with magnetic storms can be detected even in equatorial regions, although the characteristics exhibited there admittedly differ from those found in higher latitudes. Our first major conclusion must therefore be that magnetic and ionospheric storm events cannot be the direct effects of the incoming solar particles and their associated auroral discharges, since the former can be world-wide while the latter are localized in the high latitudes. It should here be mentioned that there is still some doubt about whether ionospheric storms are always equally developed in the northern and southern hemispheres, even at the equinoxes. But it does seem adequately proved that the ionosphere can suffer storm perturbations at places where auroral disturbances are absent.

So far, I have been concerned with ionospheric storm morphology. I now turn to theoretical matters, where much less is certain. However, the basic physical mechanism of ionospheric storm phenomena has most probably been indicated by



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D. F. Martyn. To understand this we turn again to figure 1, where are shown (*a*) a normal ionized layer profile and (*b*) a layer profile distorted by vertical expansion. Martyn has suggested that such layer deformation, which may be either an expansion or a contraction in vertical extent, is due to the ionization—electrons and positive ions alike—being moved up or down by electrodynamic forces. Let us consider in this connection, as the simplest possible example, the case at the equator, where the earth's magnetic field $H$ is horizontal. Let us assume further that there is also operative a horizontal electric field, directed, say, from west to east. Physically we may say that the horizontal electric field will cause a horizontal current in the ionosphere and that such a current element will be acted on by the earth's magnetic field, causing it to move upwards. If either the electric or magnetic field is reversed the motion will, of course, be downward. We thus see that, if the F2 layer is subject to electric forces in the presence of the earth's magnetic field, the phenomenon of drift motion arises because the ionized layer itself constitutes an electric conductor which is free to move. Generally, we may say that, if an electric field $E$, acting from west to east, operates in an ionized medium where the earth's magnetic intensity and dip are $H$ and $\varphi$ respectively, the horizontal southward drift $u$, and the vertical upward drift $v$, of the F2 layer ionization, are given, approximately, by

$$u = -\frac{E \sin \varphi}{H} \quad \ldots\ldots\ldots\ldots (4)$$

and

$$v = \frac{E \cos \varphi}{H} \quad \ldots\ldots\ldots\ldots (5)$$

These, then, are the basic equations of Martyn's theory of F2 layer distortion. He has applied them to explain the F2 layer behaviour under normal as well as storm conditions. But two further points must be mentioned. To get either the vertical expansion or distortion of an ionized layer, the vertical drift $v$ must vary with height. If $v$ is constant, the layer is merely moved bodily upwards or downwards. A basic question also is the origin of the horizontal electrostatic forces, whose existence has so far been only postulated here. To account for these, Martyn points out that the lower ionosphere (probably the lower level of the E layer) is the seat of large currents which are responsible for both the quiet-day and the disturbed-day magnetic variations, though their world configuration is different in the two cases. Martyn considers that both the normal-current system and the storm-current system in the lower ionosphere give rise to electrostatic forces which, together with the earth's permanent magnetic field, are responsible for both vertical and horizontal movements of ionization, and that it is due to the different world configurations of these electrostatic lines of force that the F2 layer effects under normal and storm conditions are different. Much work, however, remains to be done in developing these basic ideas to a full understanding of the different manifestations of F2 layer distortion at all times and at all places.

Perhaps a further comment may not be superfluous. It was at one time thought that the ionosphere was a quiet place, and that electrons appeared and disappeared at precisely the same spot. Recent work has clearly shown that this is not the case. The radio tracking of patches of ionization has indicated that horizontal motion undoubtedly takes place, while, as we have seen, ionospheric storm phenomena also indicate substantial movements of ionization in a vertical direction.

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# The Muspratts and the British chemical industry

D. W. F. HARDIE

James Muspratt is justifiably regarded as the founder of the British heavy chemical industry, and members of his family, the history of which is here reviewed, played a prominent part in it for over a century. Particular mention is made here of James Sheridan Muspratt, who established a name for himself as a talented analyst and teacher of chemistry. His great dictionary of chemical technology was for many years a standard work throughout the world and even today is a valuable source of information about nineteenth-century practice.

According to a family tradition, the Muspratts were originally immigrants from France. Official records at Somerset House, London, show that in the first half of last century there were numerous bearers of the name in the southern counties of England and in London. Although details are lacking, it seems probable that the Muspratts who appeared in Dublin directories towards the end of the eighteenth century were all members of a family group which had recently migrated from England. In the Irish capital, where the brewing industry had already reached considerable dimensions, they plied their trade of cork-cutting. One member of the Dublin branch, John Petty Muspratt, became a banker in London and attained to an influential position as a director of the East India Company, being elected by the private trade interest first in 1825 and again in 1930 [1]. Evan Muspratt, brother of the East India director, had three children—a daughter who in later life resided in America; George, of whom nothing is known; and James (b. 1793) [2].

Evan Muspratt probably gained sufficient income from his cork-cutting business to give his son James as good an education as early nineteenth-century Dublin could offer. Details of James's life-history begin to emerge only from the time of his father's death in 1810. Following her husband's death, James Muspratt's mother married John Corley of Dublin in 1811, but survived only a few months thereafter [3]. The death of both his parents, and his mother's remarriage, must have had a profound effect on the lad of eighteen years, and flight from bitterness and grief may be in great part the explanation of his seeking adventure in the war-torn Spanish peninsula [4]. Having returned to Dublin as a deserter from the Navy, James for a time joined a gay coterie associated with the Irish stage, thus developing a taste which he was to indulge to the full in later years.

In the first decades of last century, Dublin was, by the scale of chemical industry at that period, an important chemical manufacturing centre, particularly for sulphuric acid. In 1819 James Muspratt married Julia Connor, and no doubt the prospect of establishing a family provided the immediate urge for young Muspratt to forsake for a time his social life and to apply himself to the business of making chemicals. This he did in partnership with Thomas Abbot, a drug and general merchant. Friendship with the family of the future Sir Robert Kane, acid manufacturers in Dublin, may have influenced Muspratt in this.

In 1822, an Act of Parliament reducing by half the import duty on barilla was threatening seriously to reduce the advantage, *vis-à-vis* their London competitors, which Merseyside soapboilers derived from their use of untaxed native kelp. In conjunction with the circumstance that several years earlier, Tennant, at Glasgow, and Losh and Lord Dundonald, at Newcastle, had introduced on a small scale the manufacture of soda from salt by the Leblanc process, this Act was of great significance. There is some, but far from conclusive, evidence that Muspratt may have experimented with the Leblanc process in Dublin; whether he did so or not, 1823 found him in Liverpool making black ash and applying all the force of his Irish wit to persuading the neighbouring soapers to use it in place of the traditional natural alkalis. In this venture he was ultimately entirely successful, and the scale to which his operations rapidly attained justifies his being regarded as the effective founder of the British heavy chemical industry [5].

Nevertheless, despite all the distractions of industry and commerce, James Muspratt's interests continued to lie in the direction of travel and the



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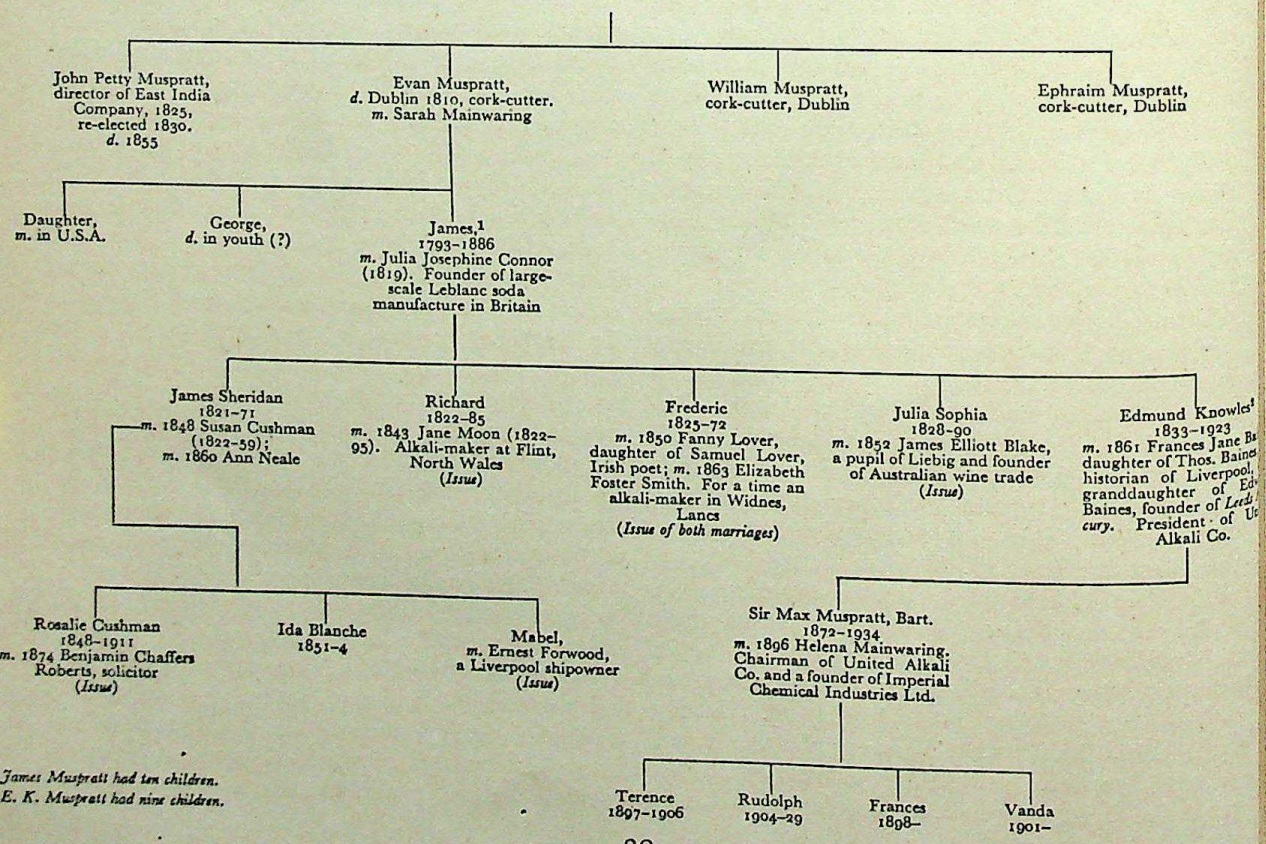
social life. As soon as, and whenever, circumstances permitted, he fled from his factories at Liverpool and Newton to seek the companionship of his friend Justus von Liebig in Germany, or the society of artists and other sun-seeking fugitives in Rome and Florence. The years of his fully active industrial life were comparatively few, extending only from the hard and hated early days in Dublin (1819–22) to 1850, but those were the years when the richest harvest was reaped from the old type of soda-making in this country. It was a period in which, despite the activity of numerous inventors, few far-reaching technical modifications took place in methods of chemical manufacture; the primitive state of chemical engineering made such progress difficult. In 1850, James Muspratt, harassed by the growing complications of carrying on the industry in the old way and by mounting claims for compensation for damage due to waste hydrochloric acid, and even by demands for closure of his factory at Newton, largely withdrew from active business.

When James Muspratt retired from alkali-making, three of his sons—James Sheridan, Richard, and Frederic—had all had experience in the soda factories. Soon after 1850 Richard established himself, in partnership with Huntley, at Flint in North Wales, where for many years he operated one of the largest Leblanc works in Britain. Frederic, with his father's support, for a time applied himself with no great enthusiasm to alkali-making at Widnes, ultimately relinquishing control to his younger brother Edmund Knowles Muspratt, who, fresh from Liebig's laboratory at Giessen, set about vigorously reorganising the Muspratt soda-making interests. When, in 1890, the Muspratt concerns in Liverpool, Widnes, and Flint, together with most of the Leblanc works in Britain, were merged in the United Alkali Company, Edmund Knowles Muspratt[1] assumed a leading part in the new concern, in which he was a dominating influence up to the period of the first world war, when total blindness afflicted him. By this time his son Max, who was created a baronet in 1922, was active in the United Alkali Company, and when, in 1926, Imperial Chemical Industries Limited was formed, Sir Max Muspratt was one of the leading industrialists

[1] E. K. Muspratt was one of a number of prominent citizens who established the University College, later University, of Liverpool; he was the first President of the Council when the University Act of Liverpool came into effect in 1903. He was also Pro-Chancellor, and he supplied the funds for the chemical laboratory.




[1] *James Muspratt had ten children.*
[2] *E. K. Muspratt had nine children.*



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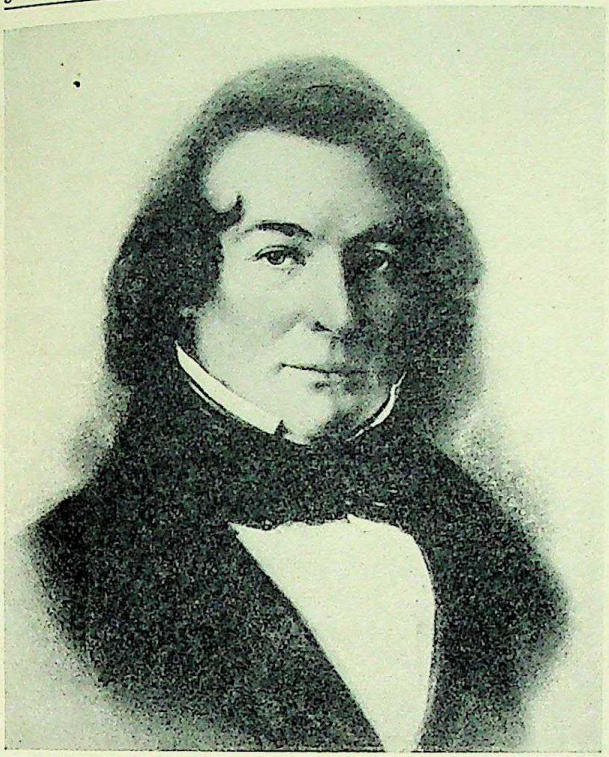

FIGURE 1 – *James Muspratt.*

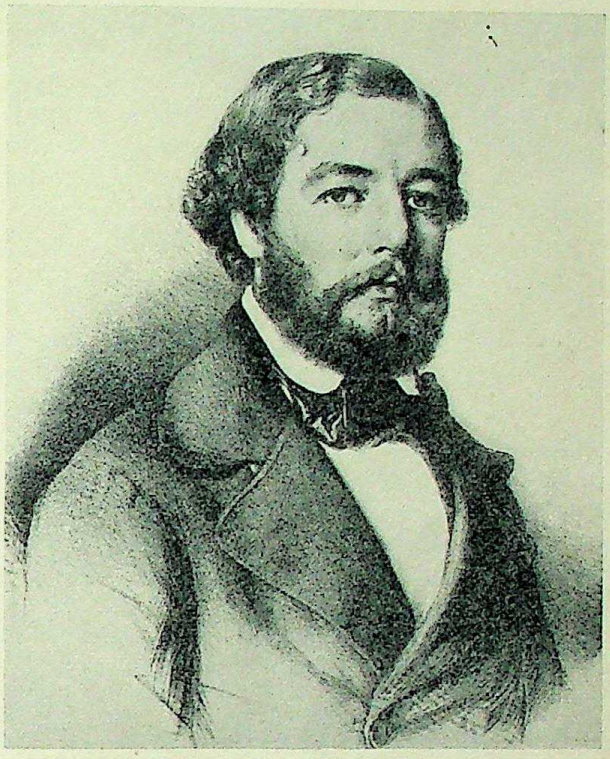

FIGURE 2 – *James Sheridan Muspratt.*

who participated in its founding. Thus, from the days of James Muspratt's small-scale chemical-making in Dublin to the third decade of the present century, the Muspratt connection with the British chemical industry was continuous.

Of the sons of James Muspratt, James Sheridan, whose story follows, was not the most successful in the commercial and industrial field. His interest was less in chemical industry than in chemistry as a science: his influence on industry was indirect, but nevertheless it was not unimportant, and he deserves his own place and recognition in its history. The name of Sheridan was a later assumption, prompted by admiration for his father's friend, James Sheridan Knowles, an actor and author who was a cousin of Richard Brinsley Sheridan, the dramatist. In what follows we shall use the name of Sheridan for the son to distinguish him unequivocally from his father.

Sheridan received his early education at private schools near his home in Bootle, and at the age of about thirteen began travels in France and Germany [6], probably in charge of one of his tutors. Through the Tennants of St Rollox, James Muspratt senior was acquainted with Thomas Graham (1805–69), then professor of chemistry at the Andersonian College in Glasgow; to this teacher he sent Sheridan in 1836, there then being in Liverpool no institution giving chemical education. Sheridan remained in Glasgow for about nine months, until Graham was elected (April 1837) to the chair of chemistry at University College, London. One of the testimonials Graham presented when canvassing his appointment was from the Liverpool alkali-maker [7].

With his brother Richard, Sheridan followed Graham to London, and there became interested in the small ammonia-soda plant being worked in Whitechapel in 1838 by Hemming and Dyar [8]. As a result of Graham's and his son's enthusiasm (restrained on Graham's part) for the new process, James Muspratt employed it for a time at his Newton works—a technological venture that lost him some £8000 [9].

Graham's pupil, Lyon Playfair—who achieved some celebrity in nineteenth-century academic chemistry—worked for a short time in the laboratory of Muspratt's factory. In the autumn of 1839 James Muspratt proposed to Playfair that he should advance him part of the requisite capital if Playfair would take Muspratt's sons into partnership in a chemical manufacturing concern. In a shrewdly couched letter [10] Playfair thanked Muspratt for his generosity, but made it clear that he must be under no obligation, if he were to



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accept it, to take the younger Muspratts as partners, and there the matter rested.

The great potentialities of a chemical export trade from the Mersey to the United States must have been evident to James Muspratt, even before a visit he made to America in 1838. In the summer of 1840, he sent his son Richard to New York, and, in the same year, Muspratt and Tennant shipped the first cargoes of soda-ash to America [11]. From this beginning grew, in the course of the next few decades, the great nineteenth-century chemical export trade from Britain. By 1850, about 60 per cent of the soda-ash made in Britain was being shipped across the Atlantic.

In the summer of 1841, following his brother's return to England, Sheridan was sent by his father to Philadelphia, where he was set up in business with one of his father's American friends, James McHenry, the firm acting as a selling agency for James Muspratt. In the first six months, Sheridan sold only 25 dollars' worth of soda-ash and 2500 dollars' worth of soda crystals. He was optimistic, however: he calculated that 'there will be $150 000 worth of ash sold' in the year to come. He conjured up visions of the commission he was to receive from these sales: 'I know that what I spend will be earned—the sweetest reflection a man can have' [12]. Sheridan was certainly spending. His sojourn in the United States cost his father several thousand pounds and did not notably advance Muspratt's commercial connection in Philadelphia. In 1842 Sheridan sailed for Liverpool.

On the occasion of the British Association's meeting at Liverpool in 1837, James Muspratt made the acquaintance of Justus von Liebig, who was one of the distinguished foreign visitors [13]. This acquaintance soon warmed into friendship. There followed, as we have mentioned, much coming and going between Giessen and the great house, Seaforth Hall, which Muspratt had built on the Mersey sand-dunes. In 1843 Sheridan's father committed him to the care of his friend Liebig. At Giessen, while entering with characteristic zest into the student life of the university, Sheridan applied himself with energy to his studies. Liebig, impressed by the ability of his pupil, entrusted him with the elucidation of the composition of certain metallic sulphides. For this work, Sheridan was awarded the degree of Doctor of Philosophy, a distinction then rarely held by foreigners. Thereafter, Sheridan for a time attached himself to A. W. Hofmann at the Royal College of Chemistry in London. He carried out with Hofmann an investigation which led to the discovery of toluidine.

At the 1837 meeting of the British Association, Liebig was asked to make a report on the state of organic chemistry. This request led, in 1840, to the publication of one of his most important works —*Die Chemie in ihrer Anwendung auf Agrikultur und Physiologie*. From that time dated Liebig's experiments to determine the nature and amounts of substances removed from the soil by growing plants, a practical consequence of which was his use of fertilizers to replace these substances. In 1845, James Muspratt took out on Liebig's behalf a British patent for the manufacture of soil additives [14]. At Muspratt's Newton works, Sheridan, with his brother Richard, made experimental amounts of the patent fertilizers. 'The entire revolution' in agriculture, confidently predicted by Sheridan, did not materialize: the fertilizers, subjected to incipient fusion in a furnace, were too insoluble to be effective.

This fertilizer venture almost brought about a serious rift in relations between Liebig and his English friends. In a confidential moment, Sheridan communicated to Dr Petzhold, a friend from his Giessen days, the formulae of the fertilizer mixtures made at Newton. By an unfortunate circumstance Liebig came to know of this indiscretion. He wrote angrily to James Muspratt: 'There lies in this an abuse of confidence placed in him [Sheridan] which must have the effect of immediately removing him from the situation he occupies. I should never have believed this had not Dr Petzhold sent me (for another purpose) the copy written by Dr James's own hand. . . . Dr James has by his criminal indiscretion cut off the possibility of introducing myself the fabrication of the manures into Germany. . . . I cannot tell how afflicted I am' [15]. Liebig's friendship survived his affliction, however; the affair was soon forgotten, along with the utter failure of the fertilizers.

Like his father, Sheridan was greatly attracted by the stage. On the occasions of visits to Liverpool by Charles Dickens' amateur company he acted as organizing secretary. In March 1847 Sheridan attended a performance of 'Much Ado about Nothing.' It was the first appearance in Liverpool of the then famous American actress, Charlotte Cushman, and her sister Susan. Shortly afterwards the Cushman sisters were guests at a fancy-dress ball at Seaforth Hall [16]. Susan's beauty and the tragedy of an early and disastrous marriage made her doubly attractive; on 22nd March 1848, Susan Cushman, then a widow, married Sheridan Muspratt, an event which brought



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the expressed approval of Alfred Tennyson [17].

In the summer of 1848, in a stable adjoining his Canning Street house, Sheridan established the Liverpool College of Practical Chemistry, his patron being no less a person than the Prince Consort himself. Liebig gave this enterprise his public blessing, testifying to Sheridan's suitability for 'the office of Professor.' The object was 'to afford at very moderate expense, *practical* instruction to students in organic, inorganic, and blowpipe chemistry, and to create chemists capable of investigating and reporting upon all subjects relating to agriculture, arts, manufactures, etc.' The term was divided into two sessions, each of eighteen weeks. Students were required to supply their own small apparatus, but reagents and gas were supplied by the professor; there was the facility of 'access to a German and English library of the best chemical works of the day' [18]. Eighteen students were soon regularly at work.

While at Giessen, Muspratt had translated into English—as 'Plattner on the Blow-pipe'—Plattner's *Probierkunst mit dem Löthrohre*, the standard work on blowpipe chemistry. This translation attracted considerable attention and probably occasioned the request, in 1854, by George Blair, a Glasgow publisher, that Sheridan should prepare an encyclopaedic work on applied chemistry, 'Chemistry, Theoretical, Practical, and Analytical, as applied to Arts and Manufacture.' The work was published in monthly parts. The editing fell heavily on Martin Murphy, an able student from Limerick, who had decided that his vocation was chemistry and not the priesthood, and who had become Sheridan's righthand man at the College. For two years Murphy worked sixteen hours a day on the dictionary. Before it was complete, Sheridan's young wife died, on 10th May 1859, an event which had a profound effect on him; for some months no new parts of the dictionary appeared. When finally published in volume form it was dedicated to J. B. Dumas and to his father's friend, the Irish chemist Sir Robert Kane [*Endeavour*, **4**, 91, 1945]. The book was an immediate success in this country and on the Continent; in America, Harvard honoured the author by conferring on him the first honorary degree of M.D. bestowed by the university on a British subject. Muspratt's dictionary was soon translated into several foreign languages, including Russian; the latest German edition appeared as recently as 1927.

About a year after the death of his wife Susan, Sheridan married Ann Neale of Rainhill, near Liverpool, who survived him. He died on 3rd February 1871 in his forty-ninth year. He was a chemist of talent rather than of genius; his researches were largely skilful analytical performances, and he failed to establish himself in a field of his own [19]. Lacking commercial ability, he chose, in place of the life of cultured idleness that could readily have been his, to be an energetic pioneer in teaching the practical science which, allied with great business acumen, had brought his father fame and fortune.

The author gratefully acknowledges his indebtedness to Mrs Permewan of Liverpool, grand-daughter of James Muspratt, for permission to make use of material from documents in her possession.

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[16] Undated newspaper cutting of a report of the ball (Muspratt papers).
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# Plant cytology and the electron microscope

A. FREY-WYSSLING

Plant cytology now covers a very wide field, and includes the study of such bodies as cell walls, cytoplasm, plastids, mitochondria, nuclei, and chromosomes. The finest structure of these has not yet been fully elucidated, but in the region of size corresponding to the range between very large molecules and the smallest particles visible by direct optical methods the electron microscope has yielded a good deal of information. This instrument may, indeed, be said to link morphology and biochemistry and to have given cell biology a new unity.

## CELL WALLS

The cell walls of plants are covered by a tough membrane which ontogenetically consists of two layers—the primary and secondary walls. The primary cell wall envelops the protoplasm of young cells during growth; towards the end of cell differentiation, however, this thin membrane becomes reinforced by the deposition of a second, thicker one having a laminated structure.

When examined by the optical microscope the primary wall appears homogeneous. It contains only a small proportion of cellulose (about 5 per cent) but large proportions of pectins and hemicelluloses, some lipophilic substances such as waxes, and even some protein. The protein disappears before the primary wall stops growing, suggesting that the latter at first contains living protoplasm but that this separates from the membrane at quite an early stage. The primary cell wall apparently grows by some form of intussusception, for it enlarges its surface considerably during cell differentiation. The study of how a solid membrane extends its area in this way is a very interesting one.

The secondary wall is quite different from the primary. It contains a high proportion of cellulose, usually more than 50 per cent; it is this which makes it the raw material for pulp-making. Under the polarizing microscope it displays a remarkable anisotropy. It grows by apposition, and for this reason is generally laminated, with layers parallel to the cell surface. It often shows striations arranged helically with respect to the axis of the cell. It has characteristic perforations, known as pits; these are not, however, open pores between adjacent cells but are separated by the pit membrane (figure 1), which represents the homogeneous primary wall. It was long a matter of controversy whether the pit membrane is continuous or contains perforations too small to be visible through the optical microscope. This question is an important one, for the answer determines whether the protoplasts of neighbouring cells are separated from each other or are in contact, i.e. whether they resemble animal cells or whether their interrelationship depends wholly upon the exchange of materials across an inanimate membrane.

The electron microscope enables the fine structure of the cell walls to be seen, and examination is much facilitated by the fact that whereas cellulose is chemically very resistant the other constituents of the cell walls are readily removed by dissolving or hydrolysing them. In consequence the primary cell wall can be reduced by maceration to a very thin film, which yields striking pictures after shadowing with chromium (figure 3).

Such pictures not only show that the cellulose consists of submicroscopic strands but reveal a most surprising structure. The strands are not laid down one upon another but appear to be interwoven. Sometimes there are two main directions of orientation, and then the appearance resembles the weave of a textile fabric (figure 2). The individual strands are separated from each other by relatively wide spaces, and it is these which, in the original

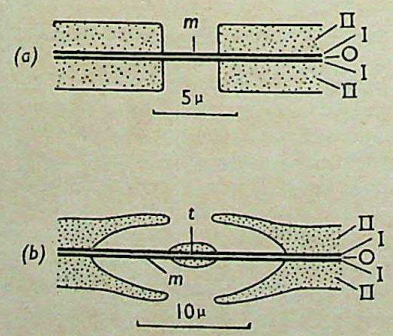


FIGURE 1 – (a) *Simple pit*, (b) *bordered pit. Key:* m = *pit membrane;* t = *torus;* o = *middle lamella;* I = *primary cell wall;* II = *secondary cell wall.*



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cell wall, contain the highly hydrated, non-cellulose constituents. In electron micrographs these spaces seem to be very much reduced, but this effect is a consequence of the mode of preparation of the material and of the nature of the instrument itself: the macerated material has to be dried before examination, and the electron microscope has a considerable depth of focus.

The cellulose strands revealed by the electron microscope have been called microfibrils [7]. By ultrasonic irradiation they can be split into even finer threads which must be elementary fibrils, because they correspond to the crystalline micellar strands disclosed by X-ray diffraction analysis.

In contrast with what is seen in the primary cell wall, the microfibrils in the secondary wall are mostly parallel with each other (figure 4); this is why this wall is denser and much richer in cellulose. Because of this structure the secondary wall can easily be split into fibrils, which represent bundles of microfibrils and are visible through the optical microscope. The so-called slip-planes (figure 4), characteristic of plant fibres, are another consequence of this structure.

The growth in area of the primary cell wall can be followed by means of the electron microscope. During mitosis the membrane appears within the cell plate, where it is formed by deposition on either side of the amorphous middle lamella. Even at this early stage it consists of interwoven microfibrils, which make contact with the primary wall of the mother cell. In the region where the longitudinal wall will be joined the texture is loosened and the microfibrils at the border of the newly formed cell plate become plaited into the weakened fabric of the lateral wall (figure 9). The latter finally breaks along a line between the attached primary membranes of the two daughter cells.

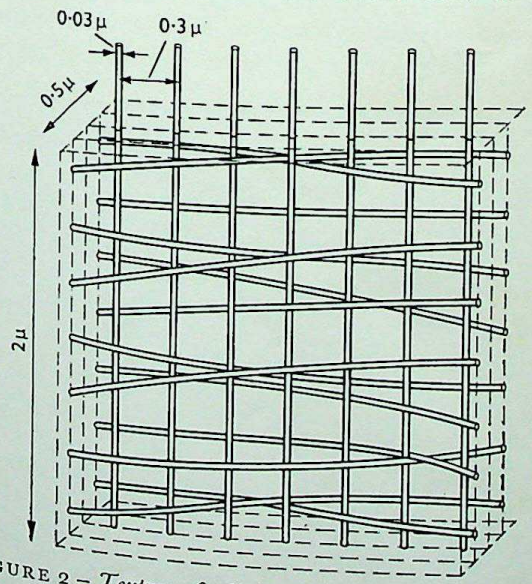

FIGURE 2 – *Texture of cellulose microfibrils in the growing primary cell wall* [3].

The walls of the new cells will for a time increase by intussusception, representing a mosaic growth, as indicated by the fact that in certain areas the interfibrillar spaces increase considerably, so that the texture is strikingly loosened (figure 10). Later these areas are repaired by the insertion of new microfibrils (figure 11). This type of growth is particularly evident when the cells increase their girth. In the longitudinal direction it is immediately followed by bipolar growth at the tips [10]; this is characterized by rapid addition of new microfibrils, at both ends of the cell, to the existing primary cell wall (figure 12). While growth at the tips goes on, the main part of the cell begins to consolidate its wall by reinforcing it with microfibrils arranged in parallel fashion (figure 5); this process begins at the edges of the cells and continues until the inner surface is covered with the secondary wall. The pit areas, however, do not share in this growth in thickness; there the primary wall becomes differentiated into submicroscopic sieves of an astonishingly beautiful texture (figures 7 and 8). Through the pores of these pit membranes submicroscopic strands of cytoplasm connect the neighbouring protoplasts. This is why the pits of adjacent cells always correspond, even though the optical microscope makes it appear that they are separated by a continuous membrane.

The internal structure of the microfibrils can be investigated by X-ray diffraction methods after they have been split up into elementary fibrils either by ultrasonic irradiation or by chemical means. The cross-section of the elementary fibrils corresponds to about one hundred cellulose molecules; the fibrils have a crystalline core, covered with para-crystalline cellulose arranged in a less orderly pattern (figure 16). The most hydrophilic plane (101) of the crystal lattice runs parallel with the surface of the protoplasm; it does not coincide with the plane of the ribbon-like cellulose chain. On sedimentation from suspension all the elementary fibrils are deposited on their (101) plane; moreover, they display a tendency towards lateral association (figure 6). All the evidence is, therefore, that they are flat. The probable structure of the microfibrils, as seen in cross-section, is indicated in figure 16, which illustrates that the organization of the plant cell wall can now be traced with some


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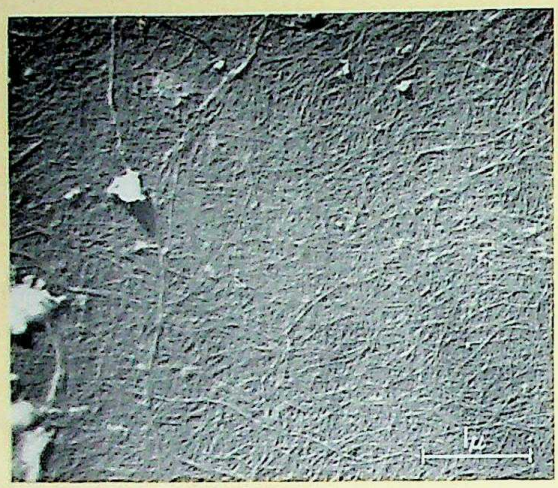


FIGURE 3 – *Primary cell wall of a linen fibre* [7].

FIGURE 4 – *Secondary cell wall of a cotton fibre* [7]. *A 'slip-plane' is visible at top left.*

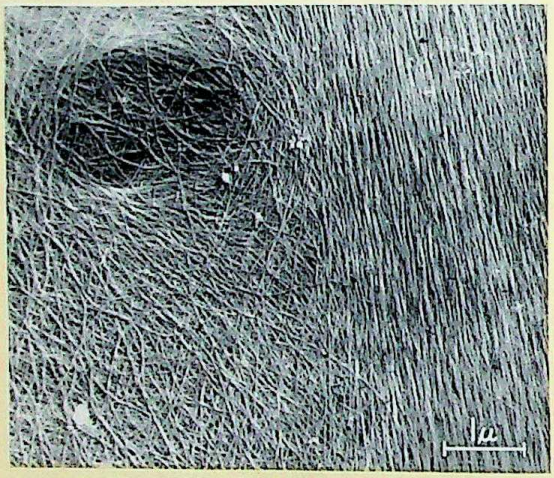


FIGURE 5 – *First deposition, in an oat coleoptile, of secondary microfibrils, arranged parallel with each other along the edge of a parenchyma cell* [10].

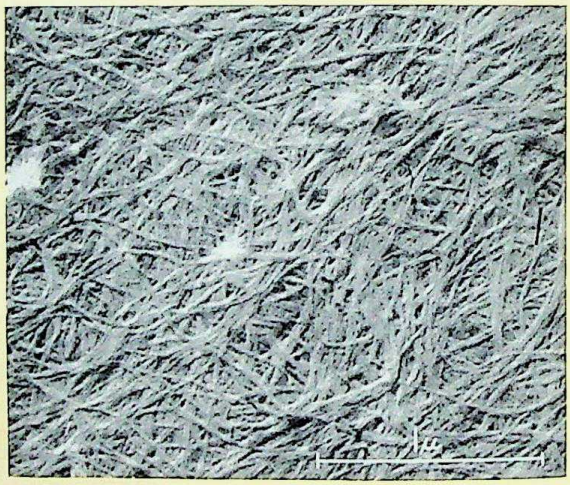


FIGURE 6 – *Lateral fasciation of microfibrils in the mesophyll cell walls of a tulip bulb* [2].

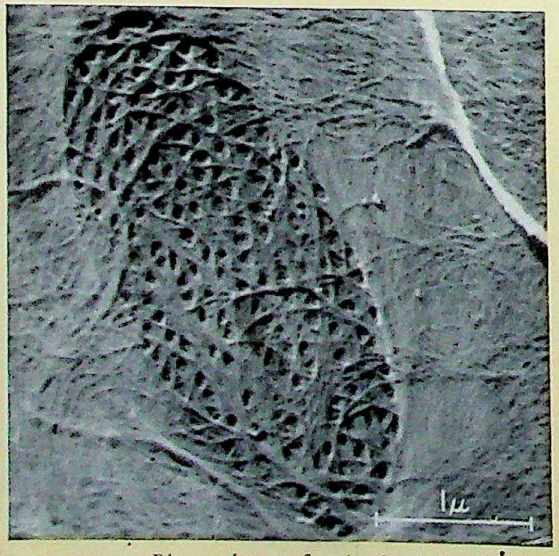


FIGURE 7 – *Pit membrane of a simple pit in the radicle of maize. (By courtesy of Dr K. Mühlethaler.)*

FIGURE 8 – *Pit membrane of a bordered pit from the wood of fir* [4].

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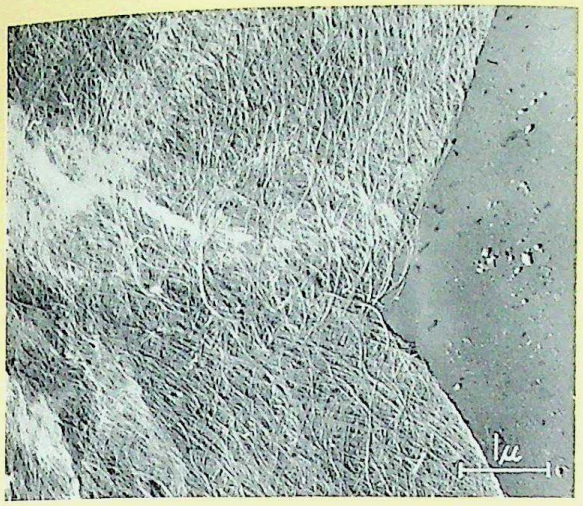


FIGURE 9 – *Fusion of the cell plate with the lateral primary wall after mitosis, in the meristem of an oat coleoptile* [6].

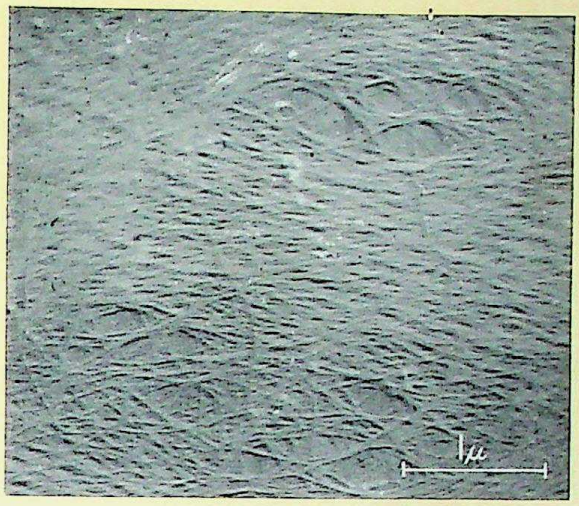


FIGURE 10 – *Mosaic growth of the primary wall in an expanding cell in the radicle of maize* [8].

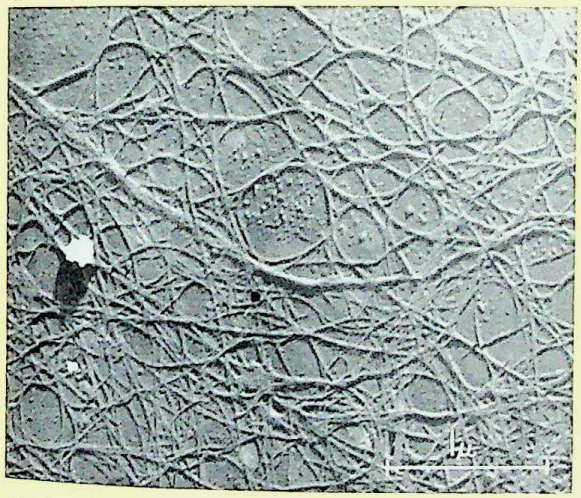


FIGURE 11 – *Intussusception in the primary wall of an expanding cell in the coleoptile of maize* [7].

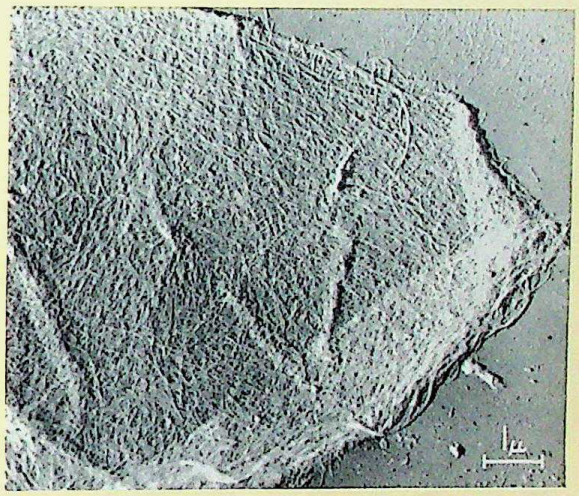


FIGURE 12 – *Tip growth of the primary wall; elongating cell in an oat coleoptile* [10].

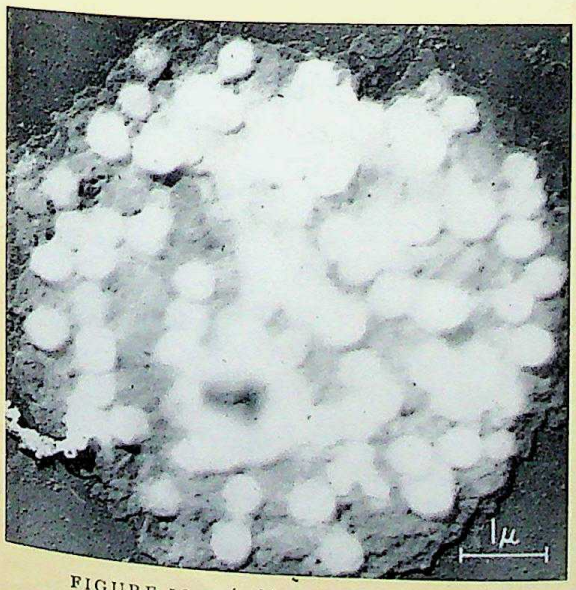


FIGURE 13 – *A chloroplast of spinach* [9].

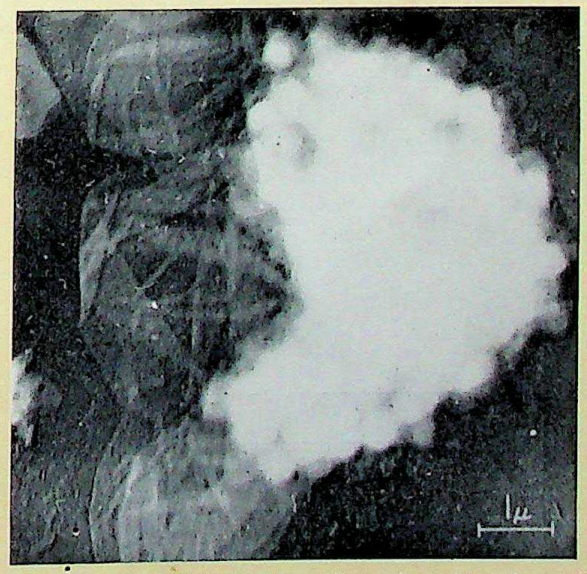


FIGURE 14 – *Unilateral swelling of a chloroplast of spinach* [9].

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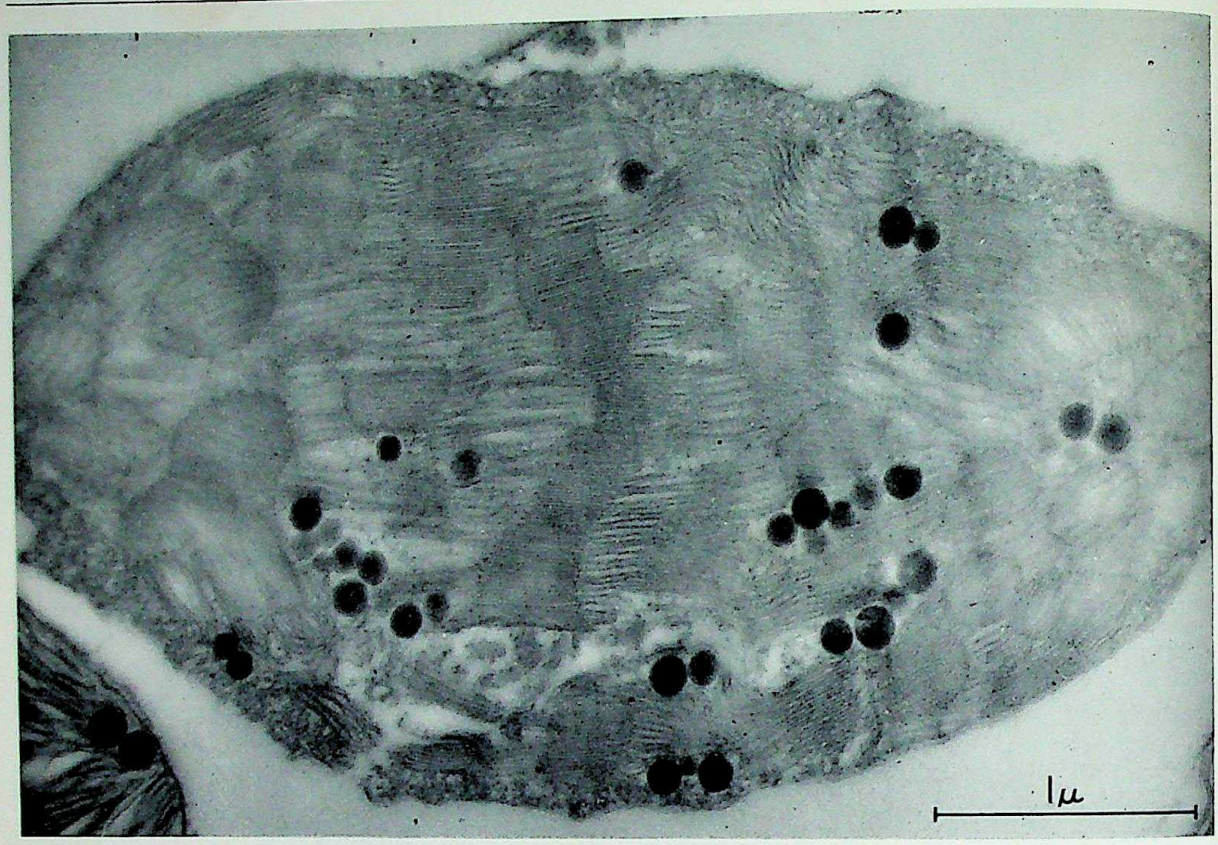


FIGURE 15 – *Ultrafine section of a chloroplast of* Aspidistra. (*By courtesy of Dr E. Steinmann.*)

confidence not merely as far as the microfibrils and elementary fibrils, but even down to the most important molecular constituent, the cellulose chain.

### CHLOROPLASTS

In the chloroplasts, the sites of photosynthesis, the chlorophyll is not uniformly distributed but is concentrated in the so-called grana, which are embedded in a colourless stroma (figure 13). Chlorophyll shows a characteristic fluorescence in ultra-violet light, in which the grana appear a deep red against a black background; in this way the stroma can be shown to be free of chlorophyll.

The grana are arranged in piles (figure 17), each consisting of a series of submicroscopic lamellae [5]. This lamination is beautifully demonstrated in ultra-fine sections cut with the Sjöstrand microtome (figure 15). The lamination is so regular that it yields X-ray patterns corresponding to a period of 250 A [1]; it is caused by piles of flat follicles which are capable of swelling [9]. Their membranes consist of globular particles, and the fine

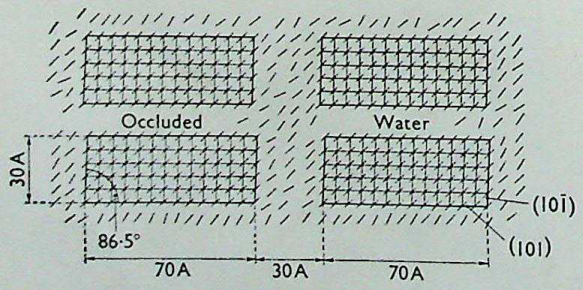


FIGURE 16 – *Section across a microfibril of native cellulose composed of four elementary fibrils. A core of crystalline cellulose chains is embedded in paracrystalline cellulose.* (101) *and* (10$\bar{1}$) *are planes of the crystal lattice* [3].

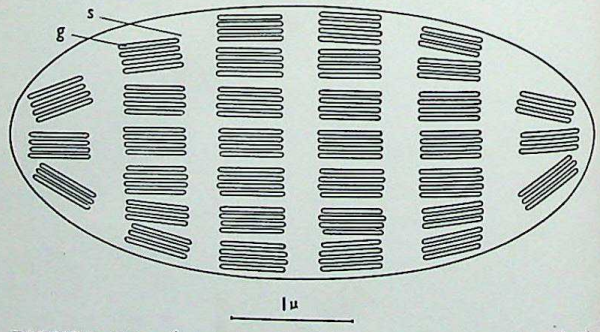


FIGURE 17 – *Arrangement of the grana in the chloroplast. Key:* g = *grana with a submicroscopic lamination;* s = *stroma.*



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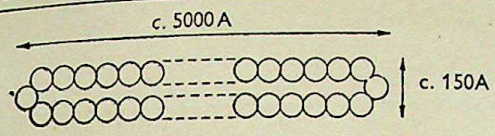


FIGURE 18 – *Macromolecular structure of one of the follicle-like double lamellae in the chloroplast grains* [9].

structure of the follicles is illustrated in figure 18. These globules represent macromolecules of the chromolipoprotein which is responsible for the capture of light energy by the chloroplasts; it is rich in pigment, containing more than 30 per cent of chlorophyll by weight.

The stroma, too, is laminated (figure 15), but its lamination is less regular than that of the grana [1]. Generally speaking, the lipoproteins of the stroma are so unstable that they can scarcely even be fixed without decomposition; in figure 15, showing a preparation fixed with osmium tetroxide, the black spheres probably represent lipids resulting from decomposition of lipoprotein.

No conspicuous membrane around the chloroplast can be demonstrated. It is apparently separated from the cytoplasm by a two-layer phase boundary similar to that in the plasmalemma or at the surface of large mitochondria. When the electron microscope seems to reveal distinct films as boundaries to the chloroplasts, these must be looked upon as artifacts due to coagulation of the lipoproteins by improper fixation. Figure 14 shows such an effect produced during the isolation of a spinach chloroplast in sucrose solution of appropriate strength; although the structure of most of the chloroplasts was conserved the one illustrated appears to be unilaterally swollen. Protein both of the stroma and of the grana has been transformed into membranes like blown-up bladders; on drying, these have fallen into the folds typical of coagulated protein membranes when viewed by the electron microscope.

## CONCLUSION

It is evident that the cell walls and the chloroplasts of plants each have their own structural characteristics. The cell membranes are built on a fibrillar principle, which appears in the macroscopic fibre strands, in the microscopic fibre cells, in the microfibrils and elementary fibrils, and finally in the cellulose molecules themselves. Although the diameter of a cellulose molecule is a million times smaller than that of a fibre strand, the architecture is fundamentally the same in both.

Linear arrangements of filaments seem to be a general principle in the skeletal substances of many types of organism. It appears not only in the cellulose of plant cell walls, but in the chitinous cell walls of fungi, in the chitinous skeletons of arthropods, in the siliceous framework of sponges, and even in the collagen which forms the connective tissue, bones, and skin of vertebrates. This general principle of construction is doubtless related to the high tensile strength of the fibrillar elements used.

In chloroplasts, on the other hand, a laminar principle is characteristic. Their location is in the blades of leaves; their shape is flat; and their submicroscopic structure is characterized by lamellae composed of molecular films of macromolecules. Here again a single characteristic morphological principle is encountered over a wide range of size. This type of structure seems obviously correlated with the capture of light energy, the principal task of the chloroplasts. The retinal rods in the eye, it may be remarked, show a similar submicroscopic lamination.

There are, however, many other structures encountered in cytology which have a laminated structure but yet have nothing to do with light absorption. As examples may be mentioned the myelin sheath of nerves, the ergastoplasm of glands, and the big mitochondria in the kidney, pancreas, and other organs. A high rate of metabolism is a common feature of most of these laminated structures, and the general purpose of lamination seems to be to facilitate exchange of energy and metabolites.

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# The colours of animals

H. MUNRO FOX

The colours of animals are due either to pigments or to the physical structure of the integument. Most pigments are synthesized by the animals, but one important group—the carotenoids—is derived from plant food. The structural colours are caused by Tyndall scattering or by interference of light. This article surveys the principal types of coloration in animals.

The coloration of animals is of great interest from several points of view. We may consider the function of the colour in the life of the animal, its chemical or physical nature, and whether colouring matters are synthesized by the animal or are derived from its food. In this article we shall be concerned mainly with the second and third of these aspects, but we may begin by briefly considering function. We must remember, however, that here our interpretations must often be speculative. Moreover, some animals can see colours as we do, others see colour that we cannot see, and yet others are colour-blind; clearly all this must be taken into account in any interpretation.

Colours and patterns may make animals either inconspicuous or conspicuous. Inconspicuous colouring enables predator or prey to escape notice: examples are the polar bear and the hare. Often the shape, which would betray the animal, is broken up by stripes, as in the tiger, or by spots as in the serval (figure 7). In a few cases the animal assists by changing its colour: a tree-frog can become more green or less green (figure 13). Conspicuous colouring is also found, and this too has its uses. It may enable animals to recognize their own kind, for mating or flocking: perhaps the moth in figure 5 and the barbet in figure 10 are examples of this. In some, for instance the peacock, the male alone is conspicuous, and he displays to the female. In the salamander (figure 9) the striking colour pattern may be a warning of an unpleasant taste, or in the sea-anemone (figure 11) of the power of stinging. In other cases the colours seem to us to be accidental, and we wonder if the beetles' metallic tints (figure 1), the lobster's blue and red (figure 6), the green and orange lower side of crabs (figure 12), the flamingo's pink (figure 14), or the colours and patterns of scallop shells (figure 15) can be of any use to their owners. Haemoglobin is red and happens to colour a few animals, such as the earthworm, the crustacean in figure 16, and so-called white man, in whom, however, blushing may be of significance. We are certain at least that the colour of the mother-of-pearl inside shells (figure 4) is useless, for in life it is invisible, and the brilliant seamouse (figure 3) lives buried beneath mud.

The colours of animals are due either to pigments or to structure. Pigments are substances which, owing to their chemical nature, absorb light of certain wavelengths and reflect light of others, and so are coloured. The red robin, yellow canary, green caterpillar, and blue lobster are coloured by pigments. But there are brilliant colours that are due not to pigments but to the physical nature of structures at the surface of animals. These are spoken of as structural colours [1], and we will consider them next.

It was Tyndall, nearly a century ago, who explained the blue colour of the sky; it is blue for the reason that very small particles in the upper air scatter back to us a higher proportion of the short waves of sunlight than of the long waves. Feathers are blue (figure 10) for a similar reason, and so are blue eyes and the blue face of a mandrill. The green colour of feathers (figure 10) is due partly to the same cause. An outer layer of yellow pigment absorbs the blue but allows the green, yellow, and red components of white light to enter the feathers. The green light is scattered by minute air spaces in the translucent feather substance to a greater extent than the longer-wave yellow and red, which are absorbed by a black internal pigment. The green of a tree-frog or lizard has a similar origin. Living cells near the skin surface contain yellow oily droplets; beneath them are cells containing tiny granules that scatter green light more than yellow or red, which are absorbed by black cells beneath those containing the granules. The species in figure 13 was named *coerulea* from a specimen which was blueish as a result of being preserved in alcohol; this coloration resulted because the yellow pigment is soluble in alcohol, and without it blue as well as green rays of light penetrate to the cells containing granules; the latter scatter blue light in



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addition to green. Proof that such blues and greens are structural colours is that when a blue or green feather is viewed by transmitted light its colour vanishes, whereas the colours of red and yellow feathers remain.

Another sort of structural coloration is to be seen in the cock's iridescent feathers, and more brilliantly in the moth of figure 5. Unlike the blues and greens just described, these colours change in hue according to the angle from which they are seen. The cause is the same as that of colours seen in soap bubbles or in films of oil on water, namely destructive interference of monochromatic components of white light reflected from two superimposed surfaces, the particular wavelengths eliminated depending upon the angle of incidence and the distance between the surfaces. In a fly's wings the iridescent colours are due to transparent layers of cuticle having different refractive indices. The brilliant colours of some beetles (figure 1) and of peacocks' feathers (figure 2) have a similar cause, and so too have the iridescent chaetae of the sea-mouse (figure 3) and the mother-of-pearl of shells (figure 4). In the moth of figure 5, and in many butterflies, the surfaces responsible for interference are layers of the transparent wing scales, and the colours instantaneously disappear when a drop of ether is put on the wing and fills the air spaces between the scales; as the ether evaporates, the colours return.

Thus the structural colours of animals may be caused by Tyndall scattering or by interference resulting from reflection from superimposed layers. In inanimate objects additional causes of non-pigmentary colours include diffraction from a grating and selective reflection from a metallic surface. Among animals, however, diffraction colours are rare, being found in a very few beetles, and selective reflection is unknown.

Whiteness can be due either to the reflection of all visible light by an opaque object of a specific chemical composition, e.g. calcium carbonate of a shell, or to reflection from numerous surfaces of a transparent substance, irrespective of its chemical composition, e.g. foam or snow. The latter phenomenon is the cause of whiteness in butterflies, which have ribbed scales, some with air-filled cavities; and of whiteness in feathers (figure 14) or hair, which have internal air-bubbles. Blackness is caused by total absorption of light; in animals this is usually due to a black pigment called melanin, seen in the salamander (figure 9), the crow, a black cat, dark human skin, and the ink squirted in defence by the octopus. It is melanin that absorbs the long-wave light in blue and green feathers, and in the green frog's skin. Melanin is insoluble and its chemical composition is not fully known, but the steps in its synthesis are partly understood. The amino-acid tyrosine, with the help of an enzyme containing copper, is oxidized by oxygen to a red indole derivative, which is then polymerized to give black melanin. Albino mammals and birds lack the enzyme, while piebalds have it in their black parts only. Light sometimes plays a part in melanin formation, as we know from the development of sunburn; thus, many animals are darker on the upper side, and if flounders are illuminated from below, they develop melanin on the underside. But the negro's skin needs no light to produce melanin, nor do frog's eggs within the body, nor octopus ink. Melanin is not always black: the yellow colour of the hair of blondes and of cats (figure 7) is said to be due to melanin. The nature of the colour of red hair, however, in redheads or chestnut horses, is not yet understood.

There is a second cause of blackness in animals, only recently explained [2]. A beetle is black because a phenol, with the help of an enzyme, becomes oxidized by oxygen to a quinone; the quinone then tans a protein in the cuticle by linking adjacent polypeptide chains, so making the protein insoluble and hard, and incidentally blackening it. This tanning process is now known to be frequent in invertebrate cuticles.

Melanin is synthesized by animals themselves, but there is a very widespread type of pigment which animals seem unable to make themselves and is derived from plant food. This derivation is apparent in the colour of egg yolk or butter, which varies with the animal's diet. These pigments were formerly called lipochromes because they are soluble in fat and fat-solvents; they are now known as carotenoids, since they have been shown to be related to the colouring matter of the carrot. Carotenoids, of which the best known are carotene and xanthophyll, are widespread in plants: many yellow flowers, and fruits such as the tomato, are coloured by them; they are present also in the green parts, where they are normally concealed by chlorophyll but are visible, for example, in ripe corn. The carotenoids can be separated by utilizing their differing solubilities and by chromatography: subsequent spectroscopy can confirm identification. Chemically, the molecule consists of a long, conjugated hydrocarbon chain terminating at each end in a ring [3]. Most of the yellows and reds of feathers, and of yellow



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beaks (figure 10), are due to carotenoids, and so is the outer yellow layer involved in the green coloration of feathers and of frog's skin. The goldfish's skin and the newt's belly are pigmented by orange carotenoids, while salmon muscle and flamingos' feathers (figure 14) are coloured by a pink variety. Very frequently carotenoids in animals are united with proteins. These carotenoid-proteins are soluble in water and have many colours. The lobster's blue shell and red antennae (figure 6), for instance, and the green and orange of shore crabs (figure 12), are due to carotenoid-proteins. The bright red colour which appears when a lobster or crab is cooked is that of a carotenoid, a derivative of astaxanthene, which has separated from its protein after the latter has been coagulated by heat. There is even a colourless carotenoid-protein: a living prawn has a colourless shell and skin, but after boiling these structures become pink, as in the lobster.

All carotenoids of animals seem to be derived ultimately from plant food, and not to be synthesized by the animals. Astaxanthene, however, is rarely found in plants and must be formed in crustaceans from a plant carotenoid. Animals often get their carotenoids indirectly from plants by eating herbivorous prey. The red skin-spots, and occasional pink muscle, of trout are due to astaxanthene. Feeding captive trout with fresh-water shrimps maintains the colours, but they are lost on a diet of butcher's meat [4]; the shrimps had made their astaxanthene from a plant carotenoid. The feathers of flamingos in captivity, when renewed after a moult, are no longer pink unless shrimps have been given with the food; the shrimps got their carotenoids from algae. The red colour of the sea-anemone in figure 11 is due to a carotenoid-protein; amputated tentacles of the anemone are replaced, and if shrimp is given as food the new tentacles become red, but with colourless fish as food they too are colourless [5].

Gowland Hopkins, sixty-five years ago, found in butterflies' wings substances which are allied to uric acid. Since then these compounds, now known as pterins, have been found to be widespread as animal colouring matters. Yellow xanthopterin is seen in pierid butterflies (figure 8), in wasps, and in the salamander (figure 9) [6]. Red erythropterin colours the wings of various butterflies and causes the red markings on the common frog [6]. Some pterins fluoresce in ultra-violet light, and it is well worth while looking at a butterfly collection illuminated by a lamp giving out ultra-violet but little or no visible light. The white or silvery aspect of the underside of fishes is due to the reflection of white light by microcrystalline guanine, also related to uric acid.

Quite a different chemical substance is responsible for the reddish colour of the sea-urchin's shell (figure 18). This pigment is called echinochrome; chemically it is a quinone of naphthalene, a compound with two condensed benzene rings. Echinochrome has been found in no other kind of animal, but from a plant is obtained another naphthaquinone, from which the dyestuff henna is prepared. However, a relation of the sea-urchin, a sea-lily or crinoid, living in the Jurassic sea 150 million years ago, was coloured by a violet quinone pigment having a number of condensed benzene rings; this has remained crystallized until this day [7]. The only other similar animal pigment known is the red colouring matter in the fat-body of the cochineal scale insect. Carmine is prepared from it; it is an anthraquinone, with three condensed benzene rings.

We come now to one of the best-known animal pigments, namely haemoglobin [8]. This colouring matter of our blood and of red meat is seldom responsible for the general body-colour of animals, but we ourselves, earthworms, water-fleas, and some other crustaceans (figure 16) are coloured by haemoglobin. The molecule consists of a red-coloured part, haem, united to a colourless protein. Haem is composed of four pyrroles attached together by four methene bridges to form a ring, in the middle of which is an iron atom linked to the four pyrrole nitrogens. When the iron is removed we are left with protoporphyrin. Another variety of porphyrin, with a copper atom in place of the iron of haem, is a unique red pigment which colours wing-feathers in the African touraco bird (figure 17). This pigment, turacin [9], is very soluble in weak alkali and rapidly leaches out of feathers immersed in such a solution. Turacin has two strong absorption bands, which are easily seen by looking through a feather at a light with a hand spectroscope.

The haem of our blood is continuously being broken down to bile pigment, which is excreted. This pigment is formed from the porphyrin by the oxidative breakage of one methene bridge. There are various varieties of bile pigment, with different colours, which depend on their state of oxidation. One variety colours some birds' eggs blue, and another makes the bones of the garfish green.

There are many green insects, such as caterpillars, grasshoppers, and the well known leaf-insect.



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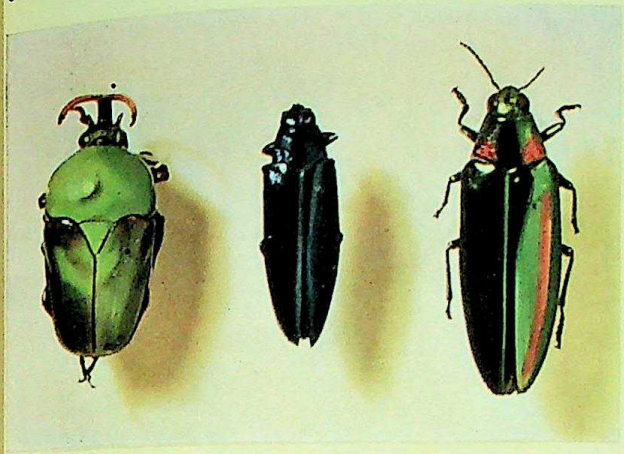

FIGURE 1 – *Beetles with structural coloration.*

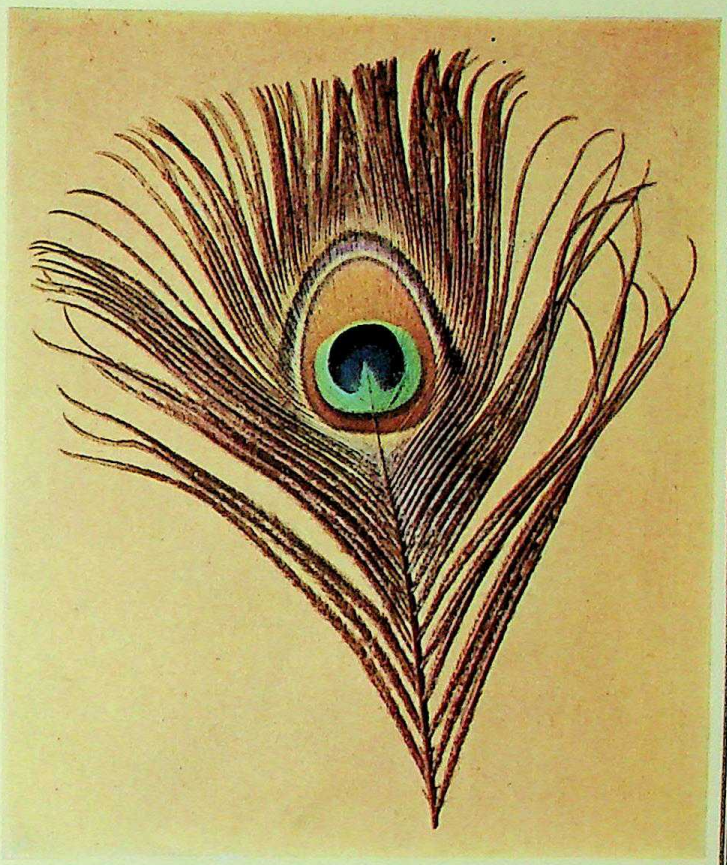

FIGURE 2 – *Peacock's feather.*

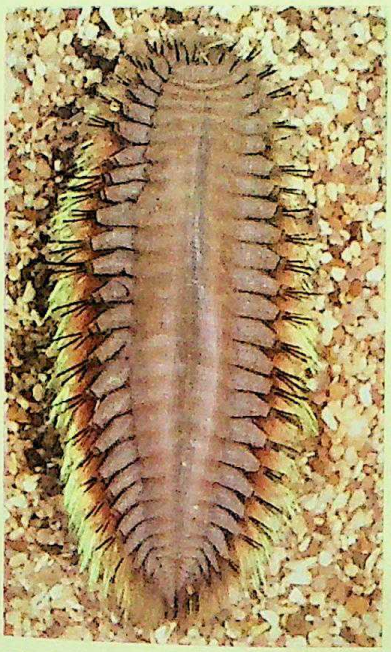

FIGURE 3 – *Sea-mouse*, Aphrodite aculeata.

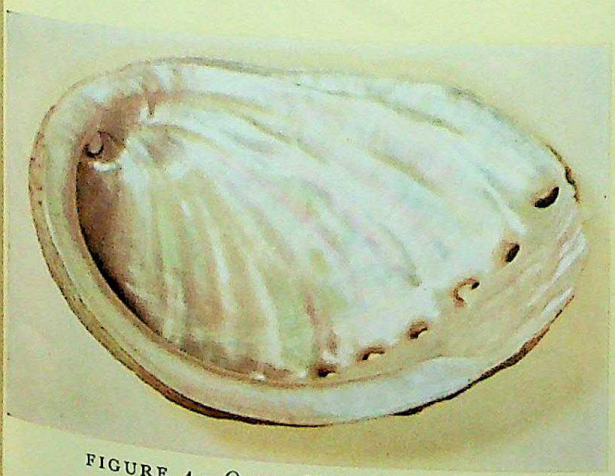

FIGURE 4 – *Ormer*, Haliotis tuberculata.

FIGURE 5 – *Day-flying moth*, Urania rhiphoeus, *from Madagascar.*

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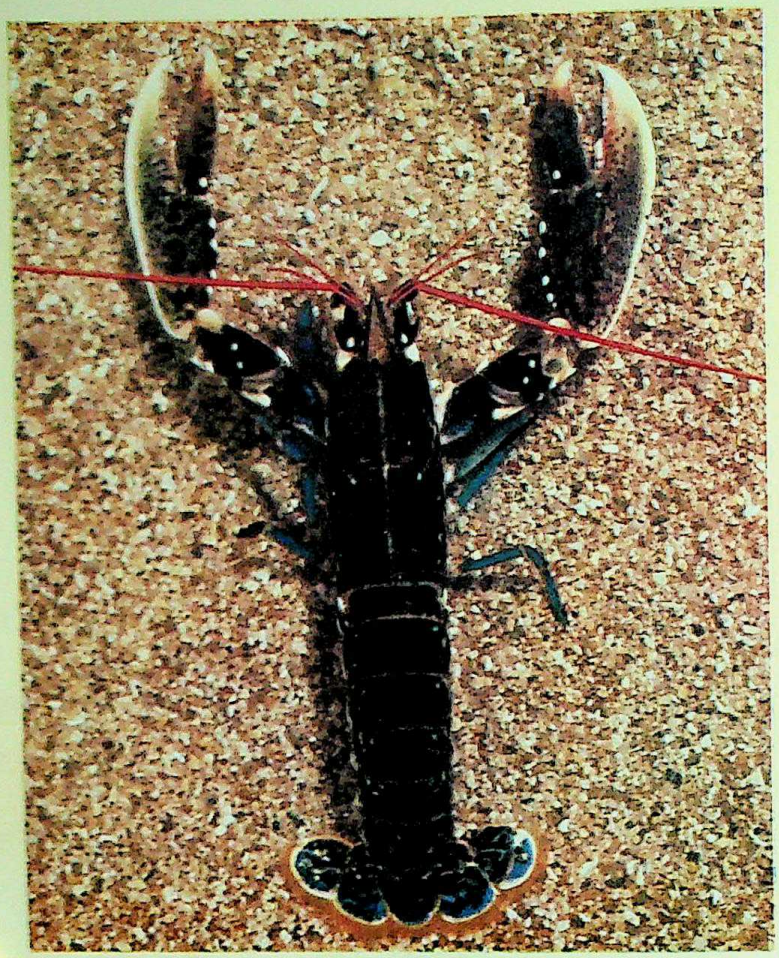

FIGURE 6 – *Lobster.*

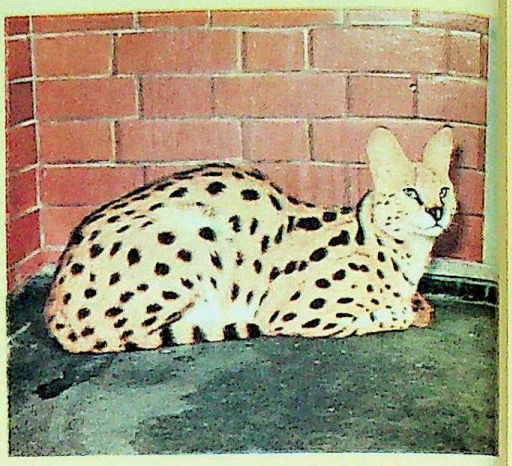

FIGURE 7 – *Serval, from Africa.*

FIGURE 8 – *Brimstone and clouded yellow butterflies.*

FIGURE 9 – *European salamander.*

FIGURE 10 – *Yellow-naped great barbet, from Himalayas.*

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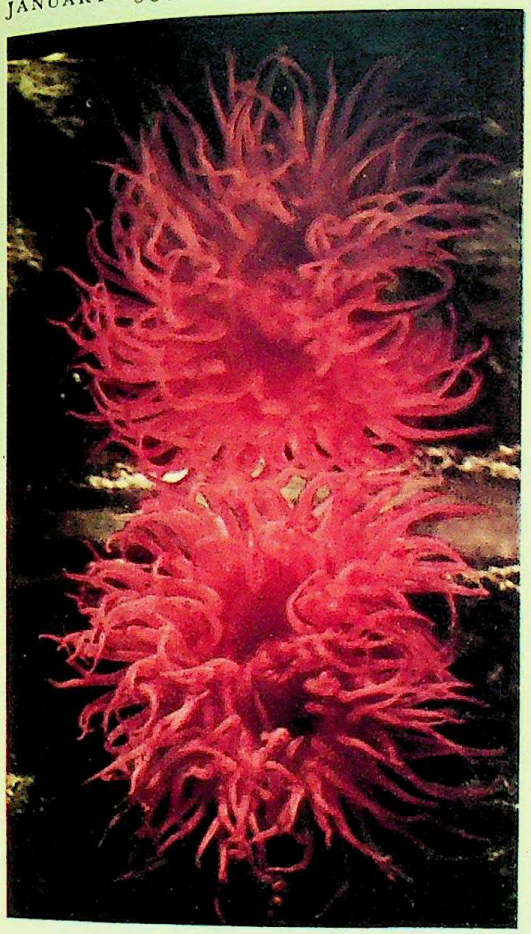

FIGURE 11 – *Sea-anemone,* Actinia equina, *with its reflection.*

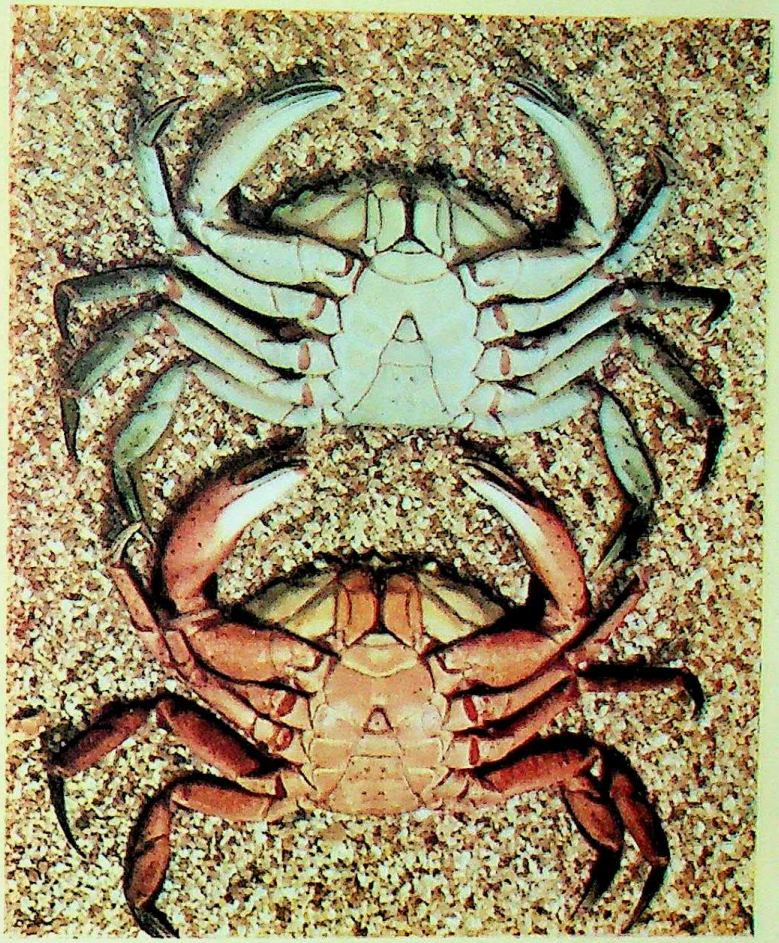

FIGURE 12 – *Shore crabs,* Carcinus maenas.

FIGURE 13 – *Australian tree-frog,* Hyla coerulea.

FIGURE 14 – *Flamingos.*

*Figures 7, 10, 11, 13, and 14 were made from photographs taken at the London Zoo.*

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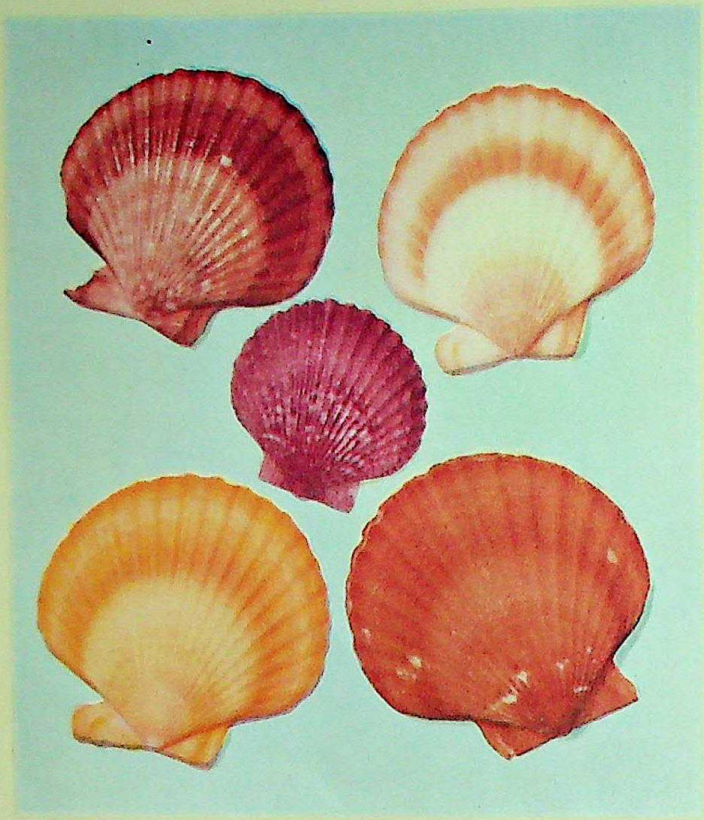

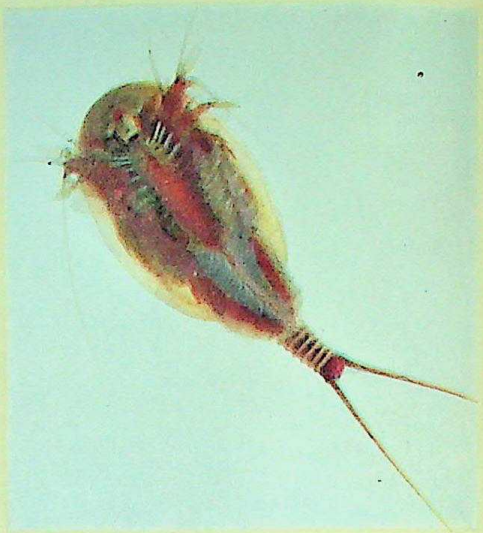

FIGURE 16 (*above*) – *Apus*, Triops cancriformis, *from Hampshire*. (Natural size)

FIGURE 15 (*left*) – *Quins*, Pecten opercularis.

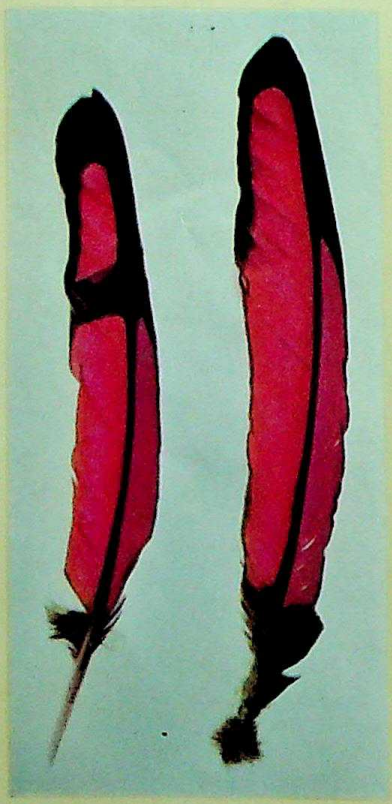

FIGURE 17 – *Feathers of a touraco.*

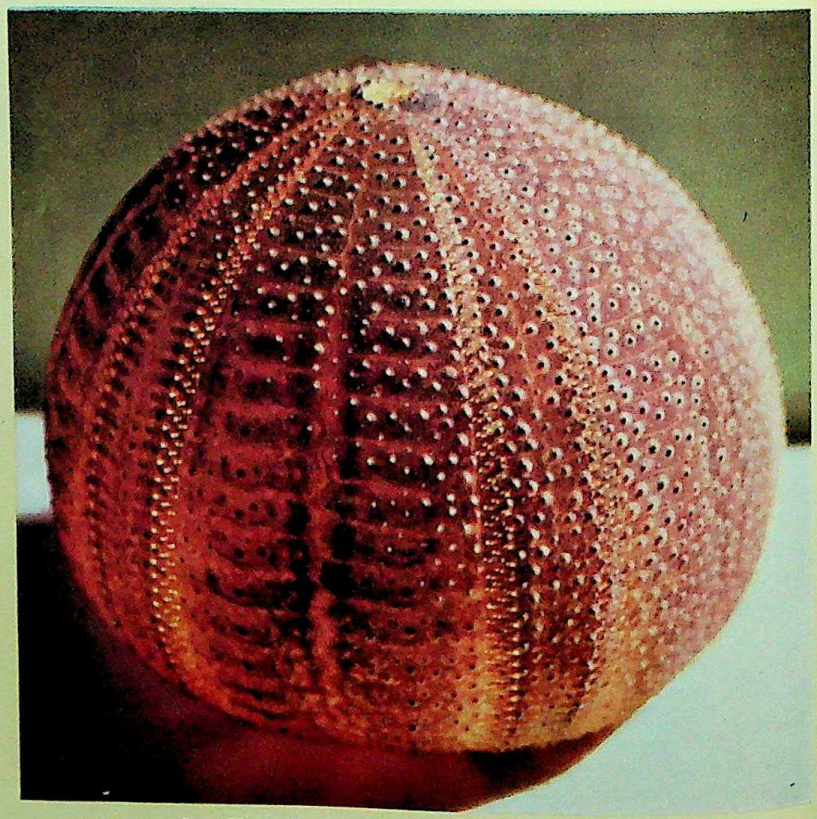

FIGURE 18 – *Test of sea-urchin*, Echinus esculentus, *lit from within.*

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It was once thought that this green colour is derived from chlorophyll in their food, but it is now known that the insects' green colour results from a mixture of a yellow with a blue pigment in the blood or skin. Such a mixture of pigments is green because the yellow pigment absorbs blue and violet, while the blue one absorbs red and yellow, but both reflect green. The insect's blue is a bile pigment and its yellow a carotenoid, both combined with proteins [10].

To summarize: blue is a structural colour in feathers, insects, and our eyes, but is due to a carotenoid-protein pigment in the lobster and to a bile pigment in some birds' eggs. Green is structural in beetles and the moth *Urania*, and partly so in feathers and frogs; it is a carotenoid-protein in crabs and a mixture of such with a bile pigment in insects. Yellow is due to a carotenoid in feathers, a melanin in hair, and a pterin in the salamander and butterflies. Red is structural in beetles; a carotenoid in sea-anemones, crabs, trout, and flamingos; a pterin in butterflies and the common frog; and it is due to echinochrome in the sea-urchin, to haemoglobin in ourselves and worms, and to a copper-porphyrin in touraco feathers. Black is caused by melanin in skin, hair, and feathers, and by a tanned protein in beetles. There remain, however, a number of animal colouring matters whose chemical nature and physiological origin are still unknown: an example of these is the beautiful coloration of the scallops seen in figure 15 and of many other shells.

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# Book reviews

### THE SOLAR SYSTEM

On the Origin of the Solar System, *by H. Alfvén. Pp. viii + 194. The Clarendon Press, Oxford.* 1954. 30*s. net.*

The theory of the origin of the solar system which is developed by Professor Alfvén in this book supposes that the planets were formed by electromagnetic action from a gas cloud surrounding the Sun, possibly the cloud from which the Sun had itself condensed. It is assumed that at that time the Sun possessed a general magnetic field; under the action of gravitation the ionized gas tended to fall towards the Sun, but the magnetic field tended to impede the fall. The elements with the highest ionization potentials became de-ionized first. As de-ionization proceeded, the non-ionized components diffused through those still ionized. Reasons are given for supposing that three, or possibly four, non-ionized clouds, differing in chemical composition, were formed, which successively fell towards the Sun.

It is supposed that in falling towards the Sun these gaseous clouds interacted in such a way that their kinetic energy was transformed into heat. Thermal ionization ensued, and when it had reached a certain limit the cloud was stopped. Angular momentum was then transferred to it from the central body, resulting in a concentration of the gas towards the equatorial plane.

The mechanism of the process by which the falling of the clouds towards the Sun was stopped is not at all clear; this is the weak point of the theory, which is entirely dependent upon its validity. If this point could be more fully substantiated, the theory would command a much wider acceptance, for it achieves a considerable measure of success in accounting not only for the main features of the planetary system but for those of the satellite systems, providing that each of the planets had a magnetic field above a certain value. The book is an important contribution to the literature on the origin of the solar system and is deserving of serious study.

H. SPENCER-JONES

### INTERSTELLAR MATTER

Nébuleuses Galactiques et Matière Interstellaire, *by Jean Dufay. Pp. 492. Éditions Albin Michel, Paris.* 1954. *Fcs.* 1650 *net.*

The study of interstellar matter, which consists partly of gas of extremely low density and partly of small solid particles, has become of great importance in astrophysics. This matter is revealed in various ways, by the bright gaseous nebulae made luminous by the stars embedded in them; by the obscuring clouds of dust, which dim or completely obscure the stars behind them; by selective absorption and scattering of the light of the stars, causing dimming and reddening; by the stationary lines in the spectra of distant stars.

An extensive and rapidly growing literature is concerned with the observations of these phenomena, their analysis, discussion, and interpretation. Physical theories differing widely in their nature and scope are involved in such problems, for instance, as the interpretation of the 'forbidden' lines



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in nebular spectra and the conclusions that can be drawn from the investigations of selective absorption about the size and nature of dust particles.

The interstellar matter is strongly condensed towards the central planes of the Milky Way and of the external galaxies. It is present in the spiral arms but not in the central nuclei. The formation of stars from this matter is still taking place, through its condensation first into grains and then gradually into larger masses.

This book by M. Dufay provides the most complete account available of the many diverse phenomena, observational and theoretical, involved in the study of the interstellar matter. It is not overloaded with mathematics, but the general principles of mathematical investigations are adequately described. The very full bibliography is useful for reference purposes. A detailed index would have added to the value of the book, but the omission of an index is not uncommon in French textbooks. The selection of plates, all from photographs taken at the observatories of Forcalquier or Haute-Provence, is good, and the reproductions are excellent.

H. SPENCER JONES

### ISOTOPES AS TRACERS

Isotopic Tracers, *by G. E. Francis, W. Mulligan, and A. Wormall. Pp. xvi + 386. University of London, The Athlone Press, London.* 1954. 37*s.* 6*d. net.*

This book is an elementary introduction to the principles and practice of isotope tracing in biological chemistry, with particular reference to medical research. As such it is an excellent book, readable and lucid. It fulfils a real need of the student or research worker with biological training and interests who, though faced with a problem suitable for tracer technique, is naturally reluctant to embark upon methods largely based on recent research in nuclear physics. This need has been ignored by some earlier writers who have erred, perhaps, on the formal side in their treatment of the basic physics. Professor Wormall and his colleagues have clearly been inspired by a sympathy for the biological reader and by their first-hand experience in biochemical tracing.

The title of the book might usefully have been more specific. For example, there is scarcely any mention of the important and elegant applications of isotope tracers in physical chemistry and in agriculture. The larger section of the book (pp. 1–214) describes the principles of the preparation, and the properties, of radioactive and stable isotopes. There is practical discussion of the methods of isotope assay and of their safe manipulation in the laboratory. A synopsis of illustrative tracer experiments, drawn almost exclusively from the field of vertebrate metabolism, concludes this section.

The final section of the book consists of a simple practical course for students, and includes some novel exercises with serum proteins labelled with iodine-131. There are useful appendices relating to the supply and assay of radioactive isotopes. The book can be highly recommended as a practical introduction to the subject for teachers and students of biochemistry or physiology.

F. P. W. WINTERINGHAM

### GENERAL BIOLOGY

Biologia Generale, *by E. Pàdoa. Pp.* 707. *Edizioni Scientifiche Einaudi, Turin.* 1953. *L.* 8000 *net.*

This textbook of general biology is primarily intended for medical students in their first year; it is, however, a source of general, up to date and critical information and is suitable for providing the general practitioner with a biological background. It is, in fact, so readable and clear that it can be recommended as a source of detailed information to those who, although not specifically trained in biology, wish to acquire knowledge in this field.

The first part is devoted to a very satisfactory account of the structure, fine structure, chemical composition, and metabolic activities of living organisms. In particular, present knowledge of the fine structures of protoplasm and their physiological significance is summarized in a convincing way. The chapters which follow deal with reproduction, embryology, and growth; the account of the latter is up to date, and the numerous data presented are linked together critically.

The chapters on genetics, evolution, and classification are relatively long, and the various subjects are expounded penetratingly and make the reader acquainted not only with existing knowledge, but also with many contemporary arguments on a number of problems. The same is true of the last chapter, on ecology, which is very interesting from a general viewpoint.

The book contains an adequate bibliography covering the period up to 1953. It is well produced and, on the whole, is one of the best Italian books on biological science published in the last two years.

M. ALOISI

### GENETICS

The Biochemistry of Genetics, *by J. B. S. Haldane. Pp.* 144. *George Allen and Unwin Limited, London.* 1954. 15*s. net.*

When it was pointed out that Mendelian segregation concerned chemical differences between organisms, the foundation of a new and very exact science was laid. That happened in 1902. But only within the last twenty years has a solid structure of knowledge come into being to which we may give the name of biochemical genetics. The new science has arisen by a combination of radically different techniques and systems of inference. The important combination has been between the chemistry of genes in the cell and the chemistry of their actions, first in very large organisms and later (with quite different consequences) in very small organisms.

In the present book Professor Haldane discusses these great developments in their various aspects. He writes for biochemists, but geneticists will be equally interested. In detail he is successful, but this is a subject of varied technicality; it demands concentrated thought in the reader. It therefore needs to be presented with conviction and coherence and without affectation. Haldane's treatment is unfortunately disconnected: the essential unity is lacking. It is also interrupted by a political and personal cross-fire which distracts and discourages the serious reader, and shatters what we must suppose is the author's serious intention. Undoubtedly the result is a valuable book, but it misses being a good book.

C. D. DARLINGTON

### PROTEIN STRUCTURE

The Chemical Structure of Proteins, *edited by G. E. W. Wolstenholme and Margaret P. Cameron. Pp.* 222, *with half-tone and line illustrations. Ciba Foundation Symposium. J. and A. Churchill Limited, London,* 1953. 25*s. net.*

During the last few years the most important advances in our knowledge of the structure of proteins have been derived from the application of chemical analytical tools of great refinement. Following a stage where the main



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endeavour was to develop methods of amino-acid analysis sufficiently precise to indicate exactly the number of residues of each type present in the molecule, recent work has concentrated on ways of establishing the order of these residues along the polypeptide chains. The Ciba Foundation performed a valuable service by making it possible for the world's leading workers in this field to meet in December 1952; the volume under review, which contains the papers presented to this conference together with verbatim reports of the discussions, is to be commended as a vivid and comprehensive, yet concise, account of the status of this important and rapidly-growing subject.

The topics discussed include new protein fractionation procedures of high resolution (Craig, Stein, Porter); end-group determination (Desnuelle, Chibnall, Fromageot); chemical step-by-step degradation of polypeptide chains (Edman, Fraenkel-Conrat, D. F. Elliott, Turba, Wieland); enzymatic degradation methods (E. L. Smith); and finally studies of a number of particular substances (Synge, Felix, Boulanger, Schroeder, Grassmann). To summarize, it may be said that we now have at our disposal a number of elegant methods which in principle might solve many, or even all, problems connected with the amino-acid sequence of proteins. In fact their applications have as yet been restricted, except in a few favourable cases, but this is a situation which is rapidly changing.

J. C. KENDREW

### CHEMICAL CONSTITUTION

Chemical Constitution, *by J. A. A. Ketelaar. Pp. viii + 398. Elsevier Publishing Company, Amsterdam; Cleaver-Hume Press Limited, London.* 1953. 40*s. net.*

This very interesting book deals with the physical principles underlying our present conceptions of interatomic and intermolecular forces, illustrated by a wide variety of examples from both inorganic and organic chemistry. Quite rightly, though somewhat uncommonly, the author considers the phenomena of chemistry as a unified whole. The properties of substances are discussed and compared against the background of four types of bonding—the ionic bond, the atomic bond, the covalent bond, and van der Waals bonding. In the first category there is a wealth of data on complexes and intermolecular compounds of different sorts, and the properties of some of these substances are correlated with crystal structure. There is a clear exposition of the wave-mechanical principles of covalency, of bond energies, and of resonance; the valency bond and molecular orbital methods for treating molecular electronic configurations are surveyed critically. The reader will welcome the clear account of such topics as directed valency, multiple bond character, conjugation, and colour in terms of modern valency theory. The chapter on the metallic bond includes a simplified but instructive account of the electron theory of metals, Brillouin zones, and the properties of alloys. That on van der Waals interactions contains much of current interest on molecular compound formation and the physical properties associated with it.

This book displays a refreshing approach to the more interesting topics of chemistry and should prove stimulating not only to student readers but to others who wish to review the advancing front of chemical theory.

H. W. THOMPSON

### CATALYSIS

Catalysis, Volume I: Fundamental Principles (Part 1), *edited by Paul H. Emmett. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 80*s. net.*

This is the first of several volumes planned to show the present state of knowledge, both theoretical and practical, of catalysis. Of the eight chapters, two deal with practical methods for preparing catalysts, and with supports and promoters. A chapter on magnetism and catalysis describes methods for investigating magnetic properties, but, beyond an initial statement that many elements of major importance in catalysis show 'interesting magnetic properties,' does little to establish this connection and nothing to reveal its cause if it exists. Other chapters deal with physical adsorption and with the measurement of surface area; the latter is competent and critical with special emphasis on the *BET* method, which assumes a complete monolayer when the adsorption isotherm for gases shows a rather sudden change of direction.

The most coherent section of the book contains three chapters by Laidler, on chemisorption, on kinetic laws in surface chemistry, and on the theory of absolute reaction rates in surface reactions. The first two contain plenty of up to date experimental material; in the third the properties assumed for the surfaces are largely hypothetical, and quantitative application to actual cases is scarcely possible yet. Homogeneous catalysis is reserved for a later volume.

While very useful, this volume is in one respect disappointing; there is no serious attempt to explain why surface catalysts work, why reactions occur on them which cannot otherwise take place. Very little attention is paid to the question of how far catalytic power depends on the geometrical spacing of the surface atoms. Such a connection was suggested long ago, is intrinsically very probable, and has received much support from the work of the late Otto Beeck. None of the authors seem to realize that straining of the adsorbed molecules through lack of correspondence between the normal distance between their atoms, and the distance between the surface atoms to which they are bound, is a very likely cause for their enhanced reactivity. May we hope that this fundamental question will be properly discussed in a later volume?

N. K. ADAM

### FRENCH-ENGLISH DICTIONARY

A French-English Dictionary for Chemists (*2nd edition*), *by Austin M. Patterson. Pp. xiv + 476. Chapman and Hall Limited, London.* 1954. 52*s. net.*

The appearance of a second edition of this dictionary will be generally welcomed, for since it was first published in 1921 it has become an accepted work of reference. However, the advance of chemistry has been so rapid in the last quarter of a century, and so many completely new fields have been opened up, that inevitably many new terms have come into general use, while others have become obsolete. In the new edition the vocabulary has been increased to 42 000 terms, compared with 35 000 in the original; random sampling in search of modern terms indicated that the revision has been satisfactorily done.

TREVOR I. WILLIAMS

### FORMALDEHYDE

Formaldehyde (*2nd edition*), *by J. F. Walker. Pp. 575. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1953. 96*s. net.*

The first edition of this book on formaldehyde was published in 1944, and it has now been completely revised. It



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is comprehensive and covers ground of interest both to the pure scientist and to the manufacturer and user of formaldehyde. The chapters include ones on formaldehyde production; monomeric formaldehyde; state of dissolved formaldehyde; commercial formaldehyde solutions; physical properties of aqueous formaldehyde; distillation of formaldehyde solutions; formaldehyde polymers; chemical properties of formaldehyde; the reactions of formaldehyde with inorganic reagents, aliphatic hydroxy compounds and mercaptans, aldehydes and ketones, phenols, carboxylic acids, acid anhydrides, ketene, acid chlorides and esters, amines, amides, nitriles, hydrocarbons and hydrocarbon derivatives, and with heterocyclic compounds; detection and estimation of formaldehyde, quantitative analysis of formaldehyde solutions and polymers; hexamethylenetetramine; uses of formaldehyde, formaldehyde polymers, and hexamethylenetetramine.

This is a fascinating and stimulating book throughout. The coverage is excellent, and the reviewer has noted the absence of only one reaction of formaldehyde—its use in detecting traces of aromatic hydrocarbons by Ramsden's method. Bibliographies are given in each chapter, the total number of references being well over 2000. Printing and formulae are of the highest standard. The only errors detected are on pp. 332 and 361; in view of the evidence cited there seems no grounds for regarding the structure of hexamethylenetetramine as being in doubt (p. 404). There are author and subject indexes.

W. BAKER

### FURANS

The Furans, *by A. P. Dunlop and F. N. Peters. Pp.* 867. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1953. 144*s. net.*

This substantial volume on the furans, from the laboratories of The Quaker Oats Company, deals comprehensively with the literature and applications of these substances up to the end of 1950. Part I (700 pages) reviews the chemistry of the furans; Part II (100 pages) reviews the industrial applications of furfural and its derivatives. An appendix lists the patents on furan resins; there is a full subject index, but no author index.

The chapters in Part I are on the physical characteristics of the furans; furan and its homologues; halogen derivatives; nitro compounds, furanols and furylamines; metallic compounds; furfuryl alcohol and other furan alcohols; furfural and other fural aldehydes and ketones; furan carboxylic acids; cleavage of the furan nucleus; and catalytic reduction of furans. Benzofurans are not included.

This book contains a wealth of information and will be an indispensable reference book on furan chemistry. The field is thoroughly covered, and the frequent use of tables facilitates rapid search for particular compounds and examples of reaction types. Each chapter contains generous references to modern chemical literature; the book contains well over 5000 such references. The type and formulae are throughout excellent, and it is attractive to find that electronic mechanisms are discussed in connection with certain reactions.

W. BAKER

### ORGANIC CHEMISTRY

Lehrbuch der Organischen Chemie (*12th edition*), *by P. Karrer. Pp. xx* + 949. *Georg Thieme Verlag, Suttgart.* 1954. *DM* 59.70 *net.*

Once again Professor Karrer has revised his famous textbook and brought it completely up to date. The arrangement of subject matter follows that of the previous editions, and is based in a systematic way on the nature and number of functional groups in aliphatic, in alicyclic, and in heterocyclic compounds. Many parts of the text have undergone extensive revision, and the extra space devoted to certain topics, in particular reaction mechanisms, has entailed abbreviation in other places and the omission of the majority of the tables.

Recently developed reagents, e.g. $LiAlH_4$, are mentioned frequently; new compounds of biochemical interest, e.g. the S-acetyl derivative of coenzyme A, are discussed; and even the very recently determined structures of terramycin and aureomycin are given. Tropolones are accorded three pages, and the use of inclusion compounds of urea and of tri-*o*-thymotide for the resolution of enantiomorphous compounds is briefly mentioned. In brief, it may be said that no significant advance in organic chemistry made since the last edition has been omitted.

Karrer's book is probably the best available single-volume textbook of organic chemistry for students and research workers, and for reference purposes, and can be recommended most highly.

J. F. W. McOMIE

### HISTORY OF TECHNOLOGY

A History of Technology, *edited by Charles Singer, E. J. Holmyard, and A. R. Hall.* (*Volume* 1. *From early times to the fall of the ancient empires.*) *Pp. lxiv* + 827, *with numerous illustrations. Clarendon Press, Oxford.* £7 7*s. net.*

Some 900 pages have gone to the making of this volume, yet it is only the first of five which have been planned and already more than half completed in print or typescript. So massive a work implies endowment, and in fact the liberal benefactor is Imperial Chemical Industries Limited. But neither size nor patronage, impressive though both be, can be described as primary aspects of this ambitious scheme. The significant factor is the increasingly dominant position of technology and the technician in modern life, with the reflection of that trend in modern historical or archaeological studies as an inevitable corollary. 'How things are done and made' is the preface to 'Why they are made' and to 'What are the consequences of their making.' In other words, a causative sequence based on technology has become in a considerable measure the backbone of history, in the widest sense of the term. This great miscellany therefore fits aptly into the modern milieu, and indeed must represent for some time to come a standard work of reference for historian and archaeologist alike.

This first volume deals with preclassical times, and ranges in subject-matter from a biological account of skill as a human possession to detailed studies such as those of speech, calculation, writing, building, transport, lighting, agriculture, and astronomy. The thirty-one sections on these and other topics are contributed by recognized experts and are admirably illustrated by plates and careful line drawings. For all its wide extent and miscellaneous character the book is a great deal more than a mere encyclopaedia. Many of the individual articles are creative work and represent substantive additions to knowledge. At the same time, they are almost uniformly written in clear, sensible language intelligible to the unspecialized reader. For watchfulness in this matter, as for the sound organic planning of the work as a whole, high credit is due to the veteran historian of science, Dr Charles Singer, and to his editorial colleagues, Dr E. J. Holmyard and Dr A. R. Hall.

The price is high. Whether read as a discontinuous story of human achievement or referred to intermittently on



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specific points, the volume would have been more manageable had it been bound in two separate parts, with the further advantage that parts sold separately would have constituted a less terrifying impact upon the purse. This criticism apart, the Clarendon Press has produced a nearly faultless library-book. If in the fullness of time a very much smaller and cheaper compendium, approximating perhaps to a dictionary, could be extracted from it, more modest shelves would greatly benefit. Meanwhile let us salute a redoubtable band of scholars and a munificent patron. R. E. M. WHEELER

### EXPERIMENTAL INORGANIC CHEMISTRY

Experimental Inorganic Chemistry, *by W. G. Palmer. Pp. xx + 578. Cambridge University Press, London.* 1954. 50*s. net.*

Dr Palmer propounds the question: 'Since organic chemistry is taught mainly through the laboratory, should not inorganic chemistry be taught in the same way?' He believes that it should, and that the methods now usually followed are uninspiring and productive of boredom. Many will agree with him that the qualitative analysis of artificially compounded mixtures, and the arteriosclerotic selections of quantitative analyses, which go to form the elementary student's exercises in practical inorganic chemistry, are unlikely to stimulate the enthusiasm so generally shown for practical organic work. One of the difficulties of making an effective change is the lack of suitable textbooks, so, with commendable energy and resolution, Dr Palmer undertook the very considerable labour of writing a book in which his conceptions of how inorganic chemistry should be taught in the laboratory find practical expression. It must be said at once that he has been most successful, and it will not be surprising if the book rejuvenates the relevant part of the chemical curriculum.

After a general theoretical introduction, dealing with such topics as atomic structure, chemical linkage, interatomic separations, metallic elements, electrochemical processes, and crystal structure and habit, Dr Palmer has arranged his course in order of the groups of the periodic system (excluding group O). Each section has an introduction, followed by careful and well-tested instructions for preparative work, and many of the preparations are complemented by directions for analysis of the products, an excellent idea inasmuch as the student is likely to enjoy analysing substances he has himself prepared. The preparations vary in difficulty, but the selection is wide and very interesting. E. J. HOLMYARD

### MOLECULAR STRUCTURE

Organic Crystals and Molecules, *by J. Monteath Robertson. Pp.* 340. *Cornell University Press, Ithaca, New York.* 1953. 32*s.* 6*d. net.*

Even the original audience may benefit from the printed copy of a visiting lecturer's spoken word. What song the Sirens sang is a puzzling question, but not beyond all conjecture, yet who shall say what meaning the bell-like tones of Glasgow had in the ears of Ithaca? Lecturers have no closely defined textbook limits, and Professor Robertson, visiting Cornell, talked without encyclopaedic intent of the things he likes.

Early successes of X-ray diffraction were in inorganic chemistry. In organic chemistry only a few simple organic molecules could then be examined, but in the last twenty years alkaloids and steroids have been measured and their molecular forms revealed in a manner more complete, more quantitative, than classical methods could achieve. Ahead appears the possibility of surveying the most complex products of nature and of the laboratory. Methods which make this possible and difficulties which retard development are here described. Part I deals with technique and principles of interpretation; part II is descriptive and starts with fundamental structures, diamond, graphite, urea, hexamethylbenzene, and others which reveal basic structural arrangements in organic molecules. There follows a study of measurements of condensed-ring hydrocarbons, leading to discussion of the general relationship between bond-length and bond-character. Another chapter deals with complex and partially known chemical structures. How organic molecules build the whole crystal is considered, but emphasis is mainly on the forms of molecules.

Some parts an organic chemist might skip, omission of a favourite molecule he may regret; but there is nothing he should not enjoy. H. M. POWELL

### NEWTON

Sir Isaac Newton, *by E. N. da C. Andrade. Pp.* 140. *Collins, London.* 1954. 7*s.* 6*d. net.*

Newton was the greatest of all men of science. The standard biography was for long that published in 1855 by Sir David Bewster: it had the defect that Newton was presented as without faults of any kind, and it was superseded in 1934 by the more balanced judgment of L. T. More. The present "Brief Life" is slight compared with More, but Professor Andrade is perhaps the best living authority on the subject, and it is supremely well done. There is a brilliant account of Newton's discoveries, and at the same time a sympathetic understanding of his psychology, the great misfortune in which was a morbid fear of opposition from others. This was the source of his troubles with Hooke concerning optics, with Leibnitz on the discovery of the calculus, and with Flamsteed on astronomy. Much of the work that first appeared in 1704 in his *Opticks* had been discovered much earlier, but he would not publish it so long as Hooke lived. His law of gravitation, and the theory of the motion of the heavenly bodies based on it, might have remained his own secret if Halley and the Royal Society had not used the utmost force they could command. E. T. WHITTAKER

### THE CULTURE OF CHINA

Science and Civilisation in China, *by Joseph Needham, with the research assistance of Wang Ling. Vol. I. Pp. xxxviii + 318. Cambridge University Press.* 1954. 52*s.* 6*d. net.*

Historians of science have long bemoaned the fact that there is no even remotely adequate account of the development of science and technology in ancient and medieval China. Travellers' tales throughout the centuries have indeed ascribed numerous inventions and discoveries to the Chinese, and sufficient more trustworthy information was available to make it seem likely that Chinese craftsmen, physicians, alchemists, astronomers, and engineers were as accomplished as their Western counterparts, at least until the last three or four hundred years. There has, however, so far been no authoritative work on the subject, and it is therefore a matter of congratulation that Dr Needham has courageously attacked the problems with which it bristles. He is uniquely equipped for the task: an eminent scientist, a practical writer on the history of science, and a sinologist with a knowledge of the language and the



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people, he has the full armoury not only desirable but requisite. The complete work, of which this is the first instalment, will be in seven volumes, and the six still to be published are already completed in manuscript. Volume I serves as an introduction to the whole; in it Dr Needham discusses the Chinese language, Chinese geography and history, and the scientific contacts between China, the Middle East, and Europe during the period under review. Even by itself this book is a most valuable contribution to the study of an obscure region of the history of science; as a prelude to the more detailed studies to come it will whet the appetites of all who read it. Finely conceived, written, and produced, and fully documented, it is a book to be read by everyone interested in the development of science and civilization. The Cambridge University Press deserves our thanks for publishing so handsome and important a work at such a modest price. E. J. HOLMYARD

### CURRENCY OF CIVILIZATION

The Hand Produced Book, *by David Diringer. Pp.* 604. *Hutchinson's Scientific and Technical Publications, London.* 1953. 60*s. net.*

As a title, 'The Hand Produced Book' no more does justice to the scope of this work than 'The Alphabet' did to its predecessor; both deal with parts of one subject, the transmission of thought. In his earlier book Dr Diringer wrote of the development of techniques for recording thought: here he describes an equally important development, that in which the record was made permanent and portable.

This book is indeed, much more an account of a phase in the civilizing process than a history of any one identifiable object. To the European bibliophile the 'hand produced book' suggests perhaps the ninth-century 'Book of Kells' or, at the most ancient, the fourth-century *Codex Sinaiticus*. Dr Diringer treats of these: but for his purpose the 'book' may be a Sumerian clay tablet of the third millenium B.C.; An Egyptian hieratic papyrus of the thirteenth century B.C.; a rune-carved stick from medieval Germany; or a Mayan deerskin written in the twelfth century A.D. in Yucatan. He has assembled, and presents briefly, authoritatively, and with ample illustration and indexing, the present state of knowledge on the materials, implements, and methods of book production, from prehistoric times to the invention of printing. He deals also with some of the historical forces which have impelled the multiplication of books.

The least satisfactory feature of this book is its plan. The earlier chapters trace the development of writing and the evolution of the book, from stick, stone, and leaf to clay tablet, papyrus, or leather scroll, and parchment codex. Then, after a chapter on Greek and Latin book production, another, entitled 'The book follows religion', traces the development of book production under Western and Eastern Christianity and the sects and religions of the Near and Middle East; it includes Jewish and Arabic literature. Two chapters then deal with 'outlying regions'—the rest of Asia and America. Finally, almost a fifth of the book is devoted to 'The Anglo-Celtic Contribution'. This chapter is an interesting and thorough monograph on Insular palaeography, but disproportionately long in a work covering the whole world, and one which cannot find space for equivalent treatment of post-Carolingian book production on the Continent. M. J. S. CLAPHAM

### SCIENTIFIC THOUGHT

A History of the Sciences, *by S. F. Mason. Pp.* 520. *Routledge and Kegan Paul Limited, London.* 1953. 28*s. net.*

This new history of science is subtitled 'Main Currents of Scientific Thought', implying an emphasis on general trends and background rather than on the details of selected experimental and mathematical developments and applications. Thus there are no illustrations and few formulae.

The scope is extremely wide, and ranges from a neat summary of the sciences in the ancient civilizations and in the Far East to discussions of modern astrophysics and relativity theory. There are background chapters on medieval technology, scientific institutions, aspects of scientific nationalism, and other topics.

A theme that is developed through the work concerns 'the difference in outlook between the craft and scholarly traditions, which has existed throughout written history'. It is suggested, for instance, that the slow progress of Chinese science was influenced by the lack of contact between scholar, bureaucrat, and technician; and, in a modern context, the academic nature of Mendelian genetics is contrasted with the easier appeal to the agriculturalist of the Soviet theories of Michurin and Lysenko.

These 500 pages of close type do not make easy general reading. They form rather something in the nature of a first textbook to lead the student of the subject to further investigation, and to that end there is a good bibliography arranged under general and chapter headings.

Dr Mason's style is clear and concise. The twentieth-century scientist will particularly appreciate his grasp of modern as well as of ancient theory.

R. H. G. THOMSON

### MINERALS FOR INDUSTRY

Minerals for the Chemical and Allied Industries, *by Sydney J. Johnstone. Pp.* 692. *Chapman and Hall Limited, London.* 1954. 75*s. net.*

This is a valuable and welcome addition to industrial chemical literature. Itself a mine of information, both qualitative and quantitative, it also contains, for each class of mineral described, extensive bibliographies and references to the relevant Standard Specifications. Post-war practice is fully dealt with, and the book is as up to date as is possible, due allowance being made for the time necessary to see it through the press. A list of some 160 firms and organizations from which the author has obtained information is an indication of the pains taken to secure thoroughly reliable material.

The section on lead illustrates the general treatment. It describes the chief ores; world production, listing the contributions of the principal producers; methods of smelting; the uses of lead, with details of the qualities used for various purposes in Britain, and standard tests prescribed for metal required for various purposes, e.g. chemical lead; and lead pigments.

Many minerals which have only comparatively recently assumed industrial importance—such as those of indium, thallium, uranium, vanadium, and zirconium—are comprehensively treated. All chemists seriously interested in chemical raw materials should have ready access to this book.

TREVOR I. WILLIAMS

### INDUSTRIAL EXPERIMENTS

The Design and Analysis of Industrial Experiments, *edited by Owen L. Davies. Pp. xiv* + 637. *Oliver and Boyd Limited, Edinburgh (for Imperial Chemical Industries Limited).* 1954. 63*s. net.*



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Many books on experimental design give full accounts of different designs but no guidance on how to choose one to suit a particular problem. Dr Davies and his colleagues not only provide an excellent textbook but offer invaluable advice on the circumstances in which various types of experiment are specially suitable; their argument is illustrated by discussion of over forty experiments in industrial chemistry. They give particular prominence to factorial designs, emphasizing their economy and the advantages of putting extra factors into an experiment. A short chapter on sequential experiments is a useful introduction to a rapidly developing field. Most interesting of all, perhaps, is the long, clear account of new techniques for estimating optimal conditions, for the development of which Dr Box, one of the authors, has been largely responsible.

Undoubtedly this book, the best yet published on statistical aspects of industrial experimentation, will help every industrial scientist. Statisticians also can learn from it a more realistic attitude to design, whether for industrial or for other research. The authors rightly insist first, that much quantitative research is inevitably statistical, and secondly, that 'a good experimental design is one which furnishes the required information with the minimum of experimental effort'. D. J. FINNEY

### GENERAL PATHOLOGY

Lectures on General Pathology, *edited by Sir Howard Florey. Pp.* 733. *Lloyd-Luke (Medical Books) Limited, London.* 1954. 63*s. net.*

The twenty-seven lectures published in this book were written by ten masters of their subjects for students at Oxford who had already taken an honours degree in physiology and biochemistry, and who had therefore some experience of the experimental approach to biological problems. The course of lectures lasted for two terms. The writers are to be congratulated on their work, and so, incidentally, are the publishers for the way in which the text and the numerous illustrations have been produced.

The main lectures deal with general pathology — history, inflammation, fever, reactions of the blood to injury, antigens, and antibodies—and the pathogenicity and virulence of micro-organisms. There are lectures also on more biochemical aspects of the subject, such as haemorrhage, shock, and oedema, and two chapters on radiations. Some lectures will have more appeal than others, but it is almost unnecessary to say that as a whole they are stimulating and quite up to date in thought and outlook. Curiously enough, however, there are no lectures on tumours and their general effects upon the body, and a lecture on the pathology involved in deviations from the normal plane of nutrition would have been useful. Had these been included, however, we might have had to forgo Sir Howard Florey on the inflammation of mucous membranes and G. R. Cameron and E. P. Abraham on degenerative changes—which would have been very undesirable. Perhaps one day the syllabus will be extended to cover three terms.

Each lecture concludes with a list of original references, and there are both a subject and an author index in the book, the former useful but perhaps not sufficiently complete. The lectures will be appreciated by many more than those for whom they were written and delivered. R. A. McCANCE

### METALS AND ALLOYS

The Structure of Metals and Alloys, *by William Hume-Rothery and G. V. Raynor. Pp. viii* + 363. *The Institute of Metals, London.* 1954. 35*s. net.*

The first edition of this book was written by Hume-Rothery in 1936, and reprints with revisions have appeared at regular intervals since then; this third edition, however, though conforming to the original scheme in many respects, is really a new book. The rapid development of that part of the science of metallurgy which depends upon a knowledge of atomic structures has demanded much fuller treatments of topics included in the first edition, and in addition there are new sections on ferrous alloys and on imperfections and dislocation theory. The process of enlargement has—perhaps inevitably in a rapidly developing subject—resulted in some change of emphasis; in particular, the book is no longer used to any serious extent for the exposition of original work, but is devoted almost entirely to the presentation of material already available in the literature.

The presentation is, of course, admirably clear. Technical crystallographic and mathematical notations are avoided, presumably on the assumption that these are not familiar to the student of metallurgy; but the physicist may be forgiven if he feels somewhat overwhelmed at the wealth of detailed information about alloy systems used in establishing and illustrating the principles involved. Two aspects of the authors' treatment, noted repeatedly, seem to the reviewer to be particularly fascinating—the skilful anticipation and overcoming of beginners' difficulties, and the glimpses afforded of the way in which the subject is developing when reasons are given for abandoning or modifying some of the ideas and suggestions advanced in the 1936 edition.

Production and printing are excellent (but what happened to figure 57 on page 71?), and the price is commendably low. W. H. TAYLOR

### CHROMIUM AND ZIRCONIUM

Metallurgy of the Rarer Metals: No. 1 —Chromium, *by A. H. Sully. Pp.* 272. No. 2—Zirconium, *by G. L. Miller. Pp.* 382. *Butterworths Scientific Publications, London.* 1954. 35*s. and* 45*s. respectively.*

These two volumes, which are the first of a series on some of the less common metals, appear at a time when the strategic importance of chromium and zirconium is rapidly increasing. In chromium metallurgy, the majority of recent developments have resulted from increases in purity, themselves resulting from the engineer's demand for materials with useful properties at elevated temperatures. In the case of zirconium, the rapid increases in production and in alloy research have been prompted by the excellent resistance to chemical attack that can be obtained, and the possible application of zirconium alloys in the atomic energy field. Each book is written by an authority on the metal concerned and both provide the prospective user with a wealth of information. They should stimulate the research worker to develop the basic knowledge of these metals still further. The field covered includes the occurrence, production, casting, fabrication, physical and chemical properties of the pure metals and their alloys, and existing constitutional data; full bibliographies are included. If the present standard is maintained, one can look forward with confidence to the subsequent volumes dealing with titanium, molybdenum, platinum, manganese, and uranium. B. W. MOTT



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DEFORMATION ANALYSIS

Analysis of Deformation, *by K. Swainger. Volume* 1. *Pp. xix* + 285. *Chapman and Hall Limited, London.* 1954. 63*s. net.*

In this book a linear theory is formulated for analysing finite deformation in three dimensions. Three reference frames are used, as against one in classical elasticity. The author claims that his theory reveals deficiencies in the older theory, but this is open to doubt. The equations satisfied by the dilation $v$ and the displacement $U$ (11·15 and 11·19 on pp. 161–2) are not different from the classical equations when one considers the restriction (curl $U$ = const) imposed by the author. But this restriction is untenable; for curl $U$ is not constant in the Saint-Venant theory of torsion, nor in the case of flexure with shear. Moreover, the existence of a centre of flexure depends on curl $U$ varying across a cross-section.

Vector analysis is used throughout the text, and with a view to making the book relatively self-contained there are appendices on vector analysis and potential theory. The book is well produced and the printing is clear, but it is a pity that ornate Old English characters have been used for some of the symbols. This gives to some pages, 117 for example, a bizarre appearance, and the author's unorthodox notation in places does not make for easy reading. When, for example, one sees an expression such as

$$S : P^n : \Delta S$$

after an integral sign, one has to search thoroughly to discover the meaning. The book is surely expensive, considering that it is but the first volume.

L. S. GODDARD

SEA FISH

The Sea Angler's Fishes, *by M. Kennedy. Pp.* 524. *Hutchinson's Scientific and Technical Publications, London.* 1954. 50*s. net.*

In many branches of science, theory and everyday practice are sharply separated. Nowhere, perhaps, is this divergence more marked than in marine zoology. By no means all ichthyologists, however profound their knowledge of structure and taxonomy, have the skill and experience necessary to angle successfully for fish; equally, anglers rarely have any detailed scientific knowledge of the fish they catch, although they may be adept at knowing where, when, and how to catch them. The publication of a comprehensive book on the fish which interest British sea anglers, written by a man who has a wide zoological knowledge of fish and is also a practised angler, is therefore noteworthy. Mr Kennedy shows considerable skill in uniting ichthyology and angling in a readable and well illustrated book. Accounts of anatomical details, feeding habits, spawning, and development of the fry are enlivened by recipes for cooking the fish when caught.

A preliminary chapter on the general biology of fishes introduces the technical terms necessary for furnishing clear information about the appearance and habits of the species later described, so that in the main text technicalities are kept to a minimum. From this book all sea anglers can gain an understanding of the principles which must guide successful fishing; its lesson for zoologists is that there is much that cannot be learnt in the laboratory.

TREVOR I. WILLIAMS

BEES

The Dancing Bees; an account of the Life and Senses of the Honey Bee, *by Karl von Frisch, translated by Dora Ilse. Pp.* 183. *Methuen and Company Limited, London.* 1954. 16*s.* 6*d. net.*

This book is the English translation of its author's *Aus dem Leben der Bienen* (1953). Its clear and persuasive English, free from technical terms, leads the reader on from one remarkable feature of these astonishing insects to another. The title of the book perhaps misleads us a little, for although the dances of the honey bee—which tell the other members of the colony of the discovery of a rich source of food, how far it is away, and the direction in which it lies—are lucidly explained, the book also discusses a great deal more. Topics include the division of labour in the colony, the way a bee smells, the little 'scent bottle' it carries about, the significance of scents, the use of the eyes, the bee's sense of time, its mental capacity and how it finds its way about, the brood, the swarm, the queen and the rearing of the young, the ruthless destruction of unwanted queens, the slaughter of the drones, and the honey bee's enemies and diseases. There is, indeed, little in the life of the honey bee that does not find a place in this book, and many readers will be much interested in the patient and ingenious experiments that have so widely increased our knowledge of these remarkable and valuable insects. For comparison, we are given two chapters on the ants, wasps, bumble bees, and the solitary bees. There are plenty of line illustrations and photographs which really help the reader to understand.

G. LAPAGE

BIRDS OF JAPAN

Shinpen Nihon Chôrui Zusetsu (Illustrated Catalogue of the Birds of Japan), *by Seinosuke Uchida.* (*In Japanese.*) *Pp.* 313, *with* 65 *plates in colour. Sôgensha Publishing Company, Tokyo.* 1950. *Yen* 2200 *net.*

This is a completely revised edition of the *Nihon Chôrui Zusetsu* (an illustrated catalogue of the birds of Japan) by the same author, of which the first, three-volume, edition appeared in 1913–15, and the fourth and latest edition in 1925–7. The present work consists of four parts: the general introduction; illustrations of birds, with descriptions printed on the page opposite each illustration; descriptions of the general characteristics of each order of birds; and indexes of the scientific, Japanese, and English names of birds, together with a bibliography.

The author follows the classification of Ernest Hartert, which is also the classification adopted by the Society of Ornithology of Japan in its publication 'A hand-list of the Japanese birds' (3rd edition, 1942). The author is one of the leading Japanese authorities on ornithology, and the various editions of his works, of which this is the latest, are regarded as standards. The illustrations, of nearly 400 birds, are very well executed and even a reader who cannot read Japanese will have no difficulty, thanks to the excellent indexes, in discovering what kinds of birds live in Japan and what they look like.

K. ENOKI



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# Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

### ASTRONOMY

Le Magnétisme des Corps Célestes, Volumes I and II, *by A. Danvillier. Pp.* 171 *and* 161 *respectively. Hermann et Cie, Paris.* 1954. *Fcs* 1600 *and* 1500 *respectively.*

### BIOLOGY

Sex in Microorganisms, *edited by D. H. Wenrich, Ivey F. Lewis, and John R. Raper. Pp.* 362. *A.A.A.S., Washington, D.C.; Bailey Brothers and Swinfen Limited, London.* 1954. 51*s.* 6*d. net.*

### BOTANY

Methods of Surveying and Measuring Vegetation, *by Dorothy Brown. Pp.* 223. *Commonwealth Agricultural Bureaux, Farnham Royal, England.* 1954. 35*s. net.*

### CHEMISTRY

Biochemical Society Symposia No. 12 —The Chemical Pathology of Animal Pigments. *Pp.* 84. *Cambridge University Press, London.* 1954. 12*s.* 6*d. net.*

The Optical Properties of Organic Compounds, *by Alexander N. Winchell. Pp.* 487. *Academic Press Inc., New York; Academic Books Limited, London.* 1954. $12 *net.*

Outlines of Organic Chemistry (*third edition*), *by E. J. Holmyard. Pp.* 492. *Edward Arnold (Publishers) Limited, London.* 1954. 16*s. net.*

Porphyrins: Their Biological and Chemical Importance, *by A. Vannotti. Pp.* 258 + *xv. Hilger and Watts Limited, London.* 1954. 50*s. net.*

Structure Reports for 1950, Volume 13; *general editor, A. J. C. Wilson. Pp. viii* + 644. *A. Oosthoek's Uitgevers Mij., Utrecht.* 1954. *Fl.* 45 *net.*

The Theory of the Photographic Process (*revised edition*), *by C. E. K. Mees. Pp.* 1133. *The Macmillan Company, New York.* 1954. $21.50 *net.*

Wool: Its Chemistry and Physics, *by Peter Alexander and Robert F. Hudson. Pp.* 404. *Chapman and Hall Limited, London.* 1954. 45*s. net.*

### GENERAL

Coal, *by Wilfred Francis. Pp.* 567. *Edward Arnold (Publishers) Limited, London.* 1954. 84*s. net.*

Die Böden Afrikas, *by S. Ju. Schokalskaja.* (*Translated from the Russian.*) *Pp.* 408. *Akademie-Verlag, Berlin.* 1953. *DM.* 29 *net.*

Formation des Continents et Progression de la Vie, *by H. and G. Termier. Pp.* 132. *Masson et Cie, Paris.* 1954. *Fcs* 750 *net.*

Industrial Organization, *by Bimal C. Ghose. Pp.* 250. *Oxford University Press, London.* 1954. 14*s. net.*

Man and Energy, *by A. R. Ubbelohde. Pp.* 247. *Hutchinson's Scientific and Technical Publications, London.* 1954. 18*s. net.*

Reviews of Research on Problems of Utilization of Saline Water. *Pp.* 96. *UNESCO, Paris; Ministry of Education, London.* 1954. 10*s.* 6*d. net.*

Science and the Common Understanding (B.B.C. Reith Lectures, 1953), *by J. Robert Oppenheimer. Pp.* 127. *Oxford University Press, London.* 1954. 10*s.* 6*d. net.*

Techniques of Technical Training, *by H. R. Mills. Pp.* 195. *Cleaver-Hume Press Limited, London.* 1953. 10*s.* 6*d. net.*

### HISTORY OF SCIENCE

The Geometry of René Descartes, *translated by D. E. Smith and M. L. Smith. Pp.* 243. *Dover Publications Inc., New York.* 1954. *Paper covers* $1.50 *net; cloth covers* $2.95 *net.*

### MATHEMATICS

An Introduction to the Mathematics of Physics, *by J. H. Avery and M. Nelkon. Pp.* 178. *William Heinemann Limited, London.* 1954. 9*s.* 6*d. net.*

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# The International Geophysical Year

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Geophysics in its many different aspects depends more than most branches of science upon international co-operation for its advancement. Two great international enterprises, the first and second International Polar Years, contributed materially to our knowledge and understanding of several branches of geophysics, in particular to those concerned with the Earth's magnetism, the aurora, and meteorology. The first of the Polar Years was in 1882–3; the second in 1932–3. In both these years a number of special stations were established in the polar regions, where the disturbances in the Earth's magnetic field are greatest, the aurora is most frequently to be seen, and the two most intense storm centres of the world are found.

At the time of the second Polar Year ionospheric investigations were in their infancy, but some important observations were made, though the methods used now seem crude. As various new techniques and methods of observation have been developed since 1933, and as many of the problems in geophysics depend for their solution upon observations being made in many different parts of the world, a widespread feeling developed that a third year, devoted to a concerted attack on these problems, would be of great value.

A proposal to this effect was brought in 1950 and 1951 before the three international scientific unions chiefly concerned and endorsed by them. The International Council of Scientific Unions approved of the proposal and widened its scope to include observations in all latitudes, so that the enterprise is now designated the International Geophysical Year. An international committee was appointed to supervise the plans, and national committees have been formed by the participating countries, which now number thirty-six. It is gratifying that the Soviet Union, though not a member nation of the International Council of Scientific Unions, has accepted the invitation to participate. The World Meteorological Organization has also agreed to participate.

The special Committee for the International Geophysical Year (known as C.S.A.G.I., *Comité Spécial de l'Année Géophysique Internationale*) has decided that the 'year' shall extend from July 1957 to December 1958, and will thus follow the second Polar Year after an interval of twenty-five years. The epoch is important. The second Polar Year came at a time of minimum sunspot activity, when the Sun was in a relatively quiescent state. As the Sun passed through a minimum of activity in 1954 it will by 1957–8 be near maximum activity.

The close association between solar activity and terrestrial phenomena, such as geomagnetic disturbances, the aurora, ionospheric storms, and the vagaries of radio propagation, is well established. But there is much that is still obscure about the physical processes involved. Detailed observations of the Sun and of the variable solar features by visual, photographic, spectrographic, and radio methods will therefore form an essential part of the programme. Arrangements are being made to ensure that the Sun will be kept as nearly as possible under continuous observation from stations well distributed in longitude. The observations will include observations of the corona at high-altitude stations; measurements of the general magnetic field of the Sun and of the localized fields associated with sunspots and other disturbed areas; cinematograph patrol of solar features and chromospheric disturbances; and observations of solar emissions at radio wavelengths.

The scope of the geophysical observations to be undertaken will be much wider and much more comprehensive than during the two Polar Years. The subjects studied will include meteorology, geomagnetism, the aurora, the airglow, ionospheric physics, cosmic rays, longitude and latitude determination, glaciology, and oceanography.

The permanent stations which make observations in these subjects will naturally participate in the programme, and for the most part their observations will be extended. But these stations are not adequately distributed, and accordingly many special stations will be established at strategic points to fill in the more important gaps between the permanent ones.

Three meridian chains of stations have been planned. The first of these extends along approximately the meridian of 80° W from the Arctic, through North America, along the west coast of South America, and into the Antarctic. The second is along the meridian of 10° E, through western Europe, Tunisia, the Sahara, and the west coast of Africa to the Antarctic. The third is along the meridian of 140° E, through Soviet territory, Japan, New Guinea, and Australia. These meridian chains are of special importance for the investigation of the general circulation of the atmosphere, which forms the most important item in the programme of meteorological investigation,



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though they will also contribute to other parts of the general programme.

Special attention is being given to the Antarctic, the Arctic, and the equatorial regions. The first is a region of great interest. Its influence on global weather and on atmospheric and oceanographic dynamics needs to be investigated. Little is at present known of the aurora australis and whether its characteristics differ from those of the aurora borealis. The course of the southern zone of maximum auroral frequency has not been adequately investigated. The characteristics of the ionosphere during the prolonged absence of sunlight will be determined. Both polar regions are of special importance for geomagnetic studies. Plans have already been made for eleven stations on the Antarctic continent or below the Antarctic circle and for ten stations on neighbouring islands; it is hoped that arrangements will be made for a further five stations on the continent and three on neighbouring islands. One station will be set up at or near the South Pole. In the Arctic the zone of maximum auroral frequency is well placed for observation, and the co-operation of Soviet scientists in observations in this region is particularly welcome. Meteorology, the aurora and airglow, geomagnetism, and the ionosphere will receive particular attention. It is hoped to establish several temporary stations in Greenland.

The equatorial region is of importance in geomagnetic, ionospheric, and cosmic ray studies. The equatorial jet-current system in the upper atmosphere, whose existence seems to be required from the observed magnetic variations at stations near the geomagnetic equator, will be investigated. Observations of ionospheric critical frequencies and of cosmic rays in the equatorial region, are required to determine their dependence upon geomagnetic latitude.

Balloons will be widely used to obtain information about the density, pressure, and temperature of the atmosphere, of the wind velocities, and of cosmic ray intensities up to heights of about 20 miles. Aircraft will be used for special soundings of the ionosphere. Rockets capable of reaching heights up to 125 miles, and smaller rockets, launched from balloons or aircraft, capable of reaching heights up to 50 miles, will be equipped with a variety of recording or telemetering equipment. By such means the atmospheric data can be extended to greater heights; the composition of the atmosphere at different heights can be determined; the electrical current systems in the atmosphere, which cause some of the observed variations in the Earth's magnetic field, can be investigated; and the spectrum of the Sun in the far ultraviolet region can be photographed.

A world-wide programme of determinations of longitudes and latitudes has been included in the programme. Seasonal changes in the angular momentum carried by the winds are compensated by corresponding changes in the angular momentum of the Earth, causing a small seasonal variation in its rate of rotation. Seasonal changes in pressure, entailing the displacement of large masses of air, tilt the Earth's axis slightly and produce an annual variation in observed latitudes. These effects will be investigated in conjunction with meteorological data.

The Moon and stars will be photographed by cameras of special design, attached to telescopes at astronomical observatories, for the investigation of the changes in the Earth's rotation and for triangulating the whole Earth. It has not been possible hitherto to make accurate maps showing the continents in their proper relation to each other because the normal methods of geodetic triangulation cannot be extended across the oceans.

In addition to the normal day-by-day observations, two days in each month, to be known as Regular World Days, have been selected for concentrated observations at all stations. One of these days will be the day of new moon and the other will be at or near quarter-moon. Some additional World Days have been selected for special observations because they will be days of unusual meteoric activity or days on which an eclipse of the Sun will occur. For the investigation of atmospheric movements some periods longer than a day are desirable. During each quarter an interval of ten consecutive days, a World Meteorological Interval, has been selected for intensive meteorological observation.

Intensive observations are desirable during times of outstanding solar activity. Such times cannot be predicted, with any certainty, long in advance. A plan has therefore been formulated for an alert to be transmitted through communication networks whenever unusual solar activity seems likely to occur, as a warning that a Special World Interval is likely to be declared within the next four to six days.

The International Geophysical Year will form the greatest scheme of international co-operation in science ever planned. That it will add greatly to the knowledge and understanding of geophysical phenomena and that it will prove of great benefit to mankind is certain.



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# High-energy particle accelerators

SIR JOHN COCKCROFT and T. G. PICKAVANCE

The big machines for the acceleration of charged particles are among the most complex and costly of modern scientific devices, but there is still little general understanding of their principles and applications. This authoritative article describes the main types now in use, with some details of individual machines, and gives examples of the kinds of research for which they are needed. Of particular interest is their use for the artificial production of some of the new particles which have been identified in cosmic rays.

Only forty years ago Rutherford and his collaborators first demonstrated the nuclear model of the atom by studies of the scattering of α-particles, derived from naturally radioactive sources, by the Coulomb field of atomic nuclei. Since those days, the electrical acceleration of charged particles in large machines has contributed much to the rapid development of nuclear physics. In the early 1930's the first accelerators—the high-tension generator of Cockcroft and Walton and the cyclotron of Lawrence—accelerated protons by a few hundred kilovolts. The biggest accelerator today, at Berkeley, California, produces protons of $6 \times 10^9$ electron volts, or 6 (U.S.) billion electron volts—hence its name 'Bevatron'. (In Europe it is now the accepted practice to use GeV for $10^9$ electron volts, in place of the American BeV.) Two machines are now planned for producing protons with energies of 20–30 GeV. One of these machines is to be built in the newly constituted *Organisation Européenne pour la Recherche Nucléaire* (CERN) at Geneva. The United Kingdom is one of the twelve member states of CERN; the others are Belgium, Denmark, France, the Federal German Republic, Greece, Holland, Italy, Norway, Sweden, Switzerland, and Yugoslavia. The other machine will be built at the Brookhaven National Laboratory in the United States.

The main tasks for both existing and future machines are concerned ultimately with attempts to obtain an understanding of nuclear forces. Typical lines of attack are the study, over a wide range of bombarding energies, of the scattering of protons by protons and of neutrons by protons, and, in the larger of the existing machines, studies of the production of π-mesons and their interaction with other particles. π-mesons, which are observed in positive, negative, and uncharged forms, have masses about 280 times the mass of the electron and are unstable; their mean lives are of the order of $10^{-8}$ second (positive and negative forms) and $10^{-15}$ second (uncharged form). They are thought to play a very important part in the forces which hold neutrons and protons together in nuclei. Although the charged varieties of π-mesons were discovered in studies of cosmic rays by C. F. Powell and his collaborators at Bristol, they are produced only very weakly by cosmic rays. They can be obtained in comparative abundance when nuclei are bombarded by intense beams of particles possessing kinetic energy of some hundreds of MeV. At still higher energies other, and more massive, unstable particles, including the V-particles discovered in cosmic rays by P. M. S. Blackett's school in Manchester, are produced artificially. Many examples of these have already been observed, using the 2·8 GeV Cosmotron at the Brookhaven National Laboratory. The significance of these strange particles, which have been discovered in considerable variety in cosmic rays, is still obscure, and it is necessary to learn much more about them. The very large machines will be needed for these studies; it seems reasonable to expect considerably greater yields, and greater variety, of these particles as the available bombarding energy is increased. The 20–30 GeV machines now being planned will also produce enough energy to create pairs of particles of nucleonic mass in collisions between two nucleons, if such processes occur, as it is believed they should, with sufficient spare energy to ensure good yield and high velocity of the artificially produced particles. Studies of the properties of negative protons and of the circumstances in which they may be produced would be of very great theoretical importance.

Low-energy machines are not necessarily made obsolete by the development of bigger ones, and there is much interest in all energy ranges, including the 1 MeV region, first reached long ago. It is always necessary to examine rare processes and to strive for greater precision in experiment,



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and such work requires beams of high intensity. Machines designed to give great energies are, however, usually not the best sources of particles of lower energy, since it is necessary to sacrifice intensity, and often flexibility, in order to obtain high energies at acceptable cost. The gaps in our knowledge of nuclear phenomena are still enormous, and experiments with particles of all obtainable energies are still needed to help to fill them.

Both electrons and heavy particles, usually protons, are used in high-energy experiments. In some types of machines it is electron acceleration that is the more easily or more cheaply obtainable, but the two kinds of particles cannot be accelerated in the same machine. Protons, however, are, in general, more powerful tools in nuclear physics, and accordingly more effort has been put into the making of proton machines than of electron machines. However, there are certain electromagnetic phenomena which can be investigated only with the help of electron beams.

### General Features of High-energy Accelerators

All accelerators of high-energy particles use stepwise acceleration by radio-frequency electric fields, with the exception of the betatron; this machine has been used to accelerate electrons up to about 300 MeV by means of the electric field associated with a changing magnetic field. The central problem dominating the design of big machines is that of particle stability; this problem has two aspects. First, the particles repeatedly encounter electric fields, applied across gaps by a radio-frequency source, and it is necessary to ensure that a useful proportion of the particles continue to arrive at the gaps at times in the radio-frequency cycle when further acceleration can occur. Secondly, it is essential to adopt some means of focusing the particles into a beam, so that useful numbers pass through the gaps instead of striking solid parts of the accelerating system. The phase of the particles with respect to the radio-frequency field is influenced by the properties of the particle injection system, unavoidable constructional and similar errors, and amplitude and frequency errors in the radio-frequency field. Unwanted changes in the direction of motion of the particles are caused by injection conditions, constructional errors, and scattering by residual gas in the vacuum chamber. The relative importance of these different factors varies with the type of accelerator, but in all very big machines, where many individual accelerations occur and the total path-length of the particles is long, it is necessary to provide positive 'focusing' of both phase and direction for a proportion of the injected particles large enough to be useful. There will be stable oscillations of the phase, and therefore of particle energy and position, about certain equilibrium or synchronous values. Similarly there will be oscillations of particle position associated with the spatial focusing forces. These oscillations have a great influence on the design and performance of the machines.

The machines fall into two general groups, namely linear accelerators and closed-orbit accelerators. In linear accelerators, many gaps and many radio-frequency power sources (or, in a small machine, a single source of high power) are used to accelerate particles in a straight line. In the closed-orbit accelerators, a magnetic guide-field is used so that the same gap, or series of gaps, may be used repeatedly, with few radio-frequency sources of relatively low power. For protons or other heavy particles the closed-orbit machines (the synchrocyclotron and the proton synchrotron) are well ahead in the race for the highest energies. For electrons the linear accelerator may possibly be the machine of the future, even for the highest energies; at lower energies, from say five MeV to a few hundred MeV, its superiority over existing types of closed-orbit machines appears to be already evident.

The reason for this state of affairs is that there are difficulties inherent in the linear accelerator which are important only when protons are to be accelerated, and that there is a difficulty in the closed-orbit machine which is important only when electrons are to be accelerated. The region of phase-stable acceleration in a linear accelerator is one in which strong directional defocusing occurs. At extreme relativistic velocities, which occur at quite low electron energies, however, the motion caused by the defocusing electric forces virtually disappears, and trouble may be readily avoided after the first few MeV (in practice the first few metres) of acceleration in a linear machine. Moreover, linear accelerators of electrons may be operated at short wavelengths, usually about 10 cm, and the accelerator proper consists of a corrugated waveguide of small diameter. Compact micro-wave power sources, each giving several megawatts in short pulses, have become available by the development of klystron valves at Stanford University. On the other hand, slow particles, e.g. protons of a few hundred MeV or less, may be



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accelerated efficiently only by the use of longer wavelengths, of the order of 1 metre, and with conventional systems a large and relatively costly waveguide has to be used. Compact, efficient, high-power sources for these wavelengths have not yet been developed, and this circumstance, together with the focusing difficulty and the great success of closed-orbit machines, explains why the linear accelerator of protons has undergone relatively little development so far.

The difficulty with closed-orbit electron machines, electron synchrotrons, is that energy is radiated by the circulating electrons, and this loss of energy has to be made good by the radio-frequency accelerating system. The effect is very small with the heavier protons, even in the biggest machines now planned, but it becomes serious with electrons at energies of a few GeV. In the linear accelerator radiation loss is completely negligible, even with electrons.

## Economic Factors

The larger accelerators are exceedingly costly, and economic considerations play a very large part in determining the types of accelerator which can be used for the highest energies. For example, the Brookhaven Cosmotron, which produces 2·8 GeV protons (to be increased to 3·0 GeV), is reported to have cost $7 000 000, and the 20–30 GeV machine now being designed at Brookhaven is expected to cost $20 000 000. The magnet and its power supplies accounted for one-quarter of the cost of the Cosmotron. The particle energy in a closed-orbit machine is determined by the product of orbit radius and magnetic field strength, but the magnetic field is restricted, by saturation effects in the iron, to 20 000 gauss or less. Consequently particle energy can be increased only by increasing the orbit radius.

The synchrocyclotron has proved to be one of the most reliable and powerful accelerators ever developed, but its use is precluded for the highest energies because the magnet cost rises very rapidly with the energy required. The magnet of a 600 MeV synchrocyclotron to be built by CERN in Geneva will contain 2500 tons of steel and will cost roughly £500 000; it will have a final orbit radius of about 225 cm. The proton synchrotron, on the other hand, accelerates particles in a magnetic field which increases with time in such a way that the orbit radius remains constant. The magnet of this machine has therefore to produce a strong field only in an annular volume, with a consequent saving of steel for a given orbit radius. The Brookhaven Cosmotron is a machine of this type; its magnet contains about 2000 tons of steel for an orbit radius of about 9 metres, so that protons having four or five times the energy of those obtainable from the CERN synchrocyclotron may be accelerated, using rather less steel. However, the proton synchrotron poses many problems, concerned with maintaining particle stability, which are absent from the synchrocyclotron and, moreover, produces, with present techniques, a beam of much smaller intensity. At the highest energies now being aimed at, 20–30 GeV, even the proton synchrotron in its present form would be much too expensive, and attempts are being made to exploit a principle, recently discovered at Brookhaven and independently by N. Christophilos, a Greek scientist, which makes it possible to use a magnet gap of much smaller volume and thus to reduce the weight and cost of the magnet still further.

## Some Features of Particular Types of Accelerators

### Linear Accelerators

We are here concerned only with high-energy accelerators, and only one linear electron accelerator in this category has yet been built. This is at Stanford University, and consists of a sectioned, corrugated waveguide having a total length of 60 metres and operating at a wavelength of 10 cm. Power is supplied by twenty-one special klystrons developed at Stanford, each giving more than 10 megawatts of power in pulses of about a microsecond duration. An energy of about 600 MeV has been attained, and it is hoped to increase this to some extent in the future. Already important results on the scattering of high-energy electrons by atomic nuclei have been obtained with the help of this machine.

The biggest linear accelerator for protons now in operation is a 32 MeV machine constructed some years ago at the University of California, but a 60 MeV machine is nearly complete at the University of Minnesota. At the Atomic Energy Research Establishment, Harwell, and at Metropolitan-Vickers Electrical Company Limited, a design study has been made for a much larger machine, for protons of 600 MeV. The absence of beam-extraction problems means that, compared with a synchrocyclotron accelerating the same proton current, more intense beams of particles can be made available for experiments. This, together with the possibility of subsequent extension to higher energies, makes the high-energy



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linear accelerator for protons an attractive machine, particularly for work in π-meson physics, if it can be constructed at reasonable cost. Recent improvements in the extracted beam from the synchrocyclotron, referred to later, have, however, diminished its advantages. A proton linear accelerator for 600 MeV would be about 300 metres in length and would require 100–150 megawatts of radio-frequency power during the pulses. In the Harwell design, most of this power would have to be provided at a frequency of 400 Mc/s, and a valve development programme would be an essential part of the project. The pulse duration would be 200 microseconds, and the pulses would occur 50 times per second, so that the mean radio-frequency power required would be 1–1·5 megawatts.

### THE SYNCHROCYCLOTRON

Here the particles travel in concentric closed orbits in a steady magnetic field, and are accelerated by a radio-frequency electric field. They start with very small velocity, and therefore with very small orbit radius, and the orbit radius increases as acceleration proceeds. The orbital period increases slightly with increasing energy. Some of this increase is accounted for by the fact that the magnetic field is made to decrease slightly as the radius increases, in order to provide the necessary focusing forces, and the remainder by the relativistic increase of mass of the particles with increasing velocity. The frequency of the accelerating field is reduced slowly, during acceleration, to an extent which compensates for the increasing orbital period, so that some of the particles may remain in step with the accelerating field. It can easily be shown that, over a broad range of operating conditions, phase stability of an appreciable fraction of the injected particles can be achieved in this way. Moreover, the focusing forces produced by a slight radial decrease of the guiding magnetic field are strong enough to ensure that few particles are lost after 'trapping' into the phase-stable orbits has occurred.

This machine has been applied only to heavy particles, such as protons, and not to electrons, because electrons acquire almost the velocity of light at quite low energies, and consequently a very wide range of frequency modulation would have to be used in handling them.

There are six large synchrocyclotrons in the United States, ranging in energy from 140 to 450 MeV; one in Canada (110 MeV); one in Sweden (190 MeV); and two in Great Britain. The new Liverpool synchrocyclotron (figure 3) produces 400 MeV protons, and the Harwell machine, which has been operating since 1949, produces protons of 175 MeV (figure 4). The machine at Berkeley, California, which was the first to operate (1946), is shortly to have its maximum proton energy increased from 340 to 730 MeV. The new 600 MeV machine which is being designed for CERN at Geneva has already been mentioned.

A notable advance in synchrocyclotron technique has recently been achieved in H. W. B. Skinner's laboratory at Liverpool. A new method of beam extraction, originally proposed at Chicago some time ago but developed theoretically and experimentally by K. J. Le Couteur, A. V. Crewe, and others at Liverpool, has been applied to the new 400 MeV synchrocyclotron. Already 3 per cent of the internal beam current has been extracted; this is an improvement, by a factor of at least 1000, over previous methods, and will enormously extend the usefulness of synchrocyclotrons in high-energy research.

### THE ELECTRON SYNCHROTRON

Here the guiding magnetic field is increased with time, during acceleration by the radio-frequency field, in such a way that the orbit radius remains constant. If the electrons are injected at an energy of a few MeV, or are accelerated by betatron operation in the early stages, their velocity will be essentially constant thereafter and the frequency of the radio-frequency field may also remain constant. The magnetic field need be applied only over an annular volume, but the magnet yoke has to be laminated in order to avoid eddy-current effects as the field is varied.

In experiments with electron synchrotrons it is customary to use the *Bremsstrahlung*, the continuous spectrum of electromagnetic radiation produced when electrons are absorbed in an internal target. This high-energy electromagnetic radiation provides a powerful experimental tool. Although some success has been achieved in attempts to extract the electron beam, the technical difficulties are considerable.

There are several large electron synchrotrons in the United States, producing about 300–350 MeV, and a 350 MeV machine was recently completed in Glasgow (figure 5). A machine of this type at the California Institute of Technology produces electrons of nearly 1 GeV, and a new 5–6 GeV machine has been proposed as a joint venture by the Massachusetts Institute of Technology and Harvard University.



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THE PROTON SYNCHROTRON

This type of machine is of special interest, since with present techniques it gives the highest artificially produced particle energies. As with the electron synchrotron, the magnet is laminated, has an annular gap, and produces a field increasing with time during acceleration. However, the proton velocity increases appreciably as the energy increases, until the velocity of light is approached at energies of several GeV. It is necessary, therefore, to increase the frequency of the radio-frequency field during acceleration in order to maintain constant orbit radius, and the correlation ('tracking') of the frequency variation with the magnetic field variation has to be very accurately carried out. This introduces considerable complication that is not present in the other machines. Moreover, it is not economically possible to recycle the magnetic field very rapidly in a large magnet, and the particles are accelerated in bursts occurring a few times per minute. In contrast, the frequency variation in the synchrocyclotron can be made quite rapidly, and in that machine it is common practice to use about 100 bursts per second. As a result of these various factors the mean intensity of the particle beam of a proton synchrotron is, with present techniques, at the most one-thousandth of that of a synchrocyclotron.

M. L. E. Oliphant, when he was at Birmingham, was the first to propose the machine which later became known as the proton synchrotron. The Birmingham machine (figure 6) has been operating for some time at an energy of 1 GeV. Figure 7 is a photograph of the 2·8–3·0 GeV Cosmotron at Brookhaven. Protons are first accelerated to about 4 MeV in an electrostatic generator, and are then injected into the gap of the large magnet, where they are accelerated further during the course of about $3 \times 10^6$ circulations, made in about one second. The distance travelled in this process is about $1{\cdot}6 \times 10^5$ km. The magnet is energized in pulses by a 21 000 kVA alternator carrying a 45-ton flywheel on the driving shaft. In this way the flywheel gives up a fraction of its kinetic energy to the electrical system during the pulse, after which it is accelerated again, in readiness for the next pulse, by a relatively small motor (1750 H.P.). About 75 per cent of the stored energy in the magnet (about $10^7$ joules) is returned to the flywheel, with the help of gas-discharge switches in the alternator circuit, during the interval between pulses. The same system, with variations in detail, is used in all existing proton synchrotrons. The 6 GeV Bevatron at Berkeley, California, is even larger (figure 8). The magnet weighs 10 000 tons and the orbit radius is about 18 metres, and in this case the particles are injected from a 10 MeV proton linear accelerator. A new machine for 15 GeV, using an air-cored magnet, is being built in Australia under the direction of Oliphant.

The focusing forces, which are necessary in order to return straying particles to the correct orbits, are associated with stable oscillations of the particles about the correct orbits. As we have seen, it is an important economic consideration in the proton synchrotron to use as small a magnet gap as possible, but the space required by these oscillations, and by perturbations due to unavoidable constructional and timing errors, sets a limit to it. If the frequency of the oscillations could be increased, it is clear that the amplitude resulting from a given angular displacement of a particle would be correspondingly reduced. With the normal (constant gradient) method of focusing in a closed-orbit accelerator, particle stability requires that $1 > n > 0$ where $n$ is a parameter which describes the magnetic field distribution and is defined by

$$n = -(r/B)\,\partial B/\partial r,$$

where $B$ is the magnetic field intensity and $r$ is the orbit radius. For synchrotrons the value of $n$ is commonly about 0·6.

The frequencies of the oscillations associated with the focusing forces (the 'betatron oscillations') are:

$$f_r = (1 - n)^{\frac{1}{2}} f_0 \quad \text{(radial)}$$
$$f_v = n^{\frac{1}{2}} f_0 \quad \text{(axial)}$$

where $f_0$ is the orbital frequency. There is clearly little scope for changing the frequencies, and an increase in one will involve a decrease in the other.

M. S. Livingston, E. D. Courant, and H. S. Snyder at Brookhaven, and independently Christophilos in Greece, showed in 1952 that a net focusing effect may be achieved in a suitably arranged system which is alternately focusing and defocusing along the path of the moving particles. With $n$ numerically $\gg 1$, but with $n$ alternately positive (radially defocusing, axially focusing) and negative (radially focusing, axially defocusing), a synchrotron may be designed with much stronger focusing forces for displacement in both directions, i.e. with higher frequencies of stable oscillations, than those of the conventional synchrotron.

The frequencies of the betatron oscillations are now greater than the orbital frequency, and, as was first pointed out by J. D. Lawson at Harwell,



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the particle motion in an alternating gradient synchrotron is very sensitive to small misalignments of the individual focusing or defocusing sections of the guiding magnet. In particular, disastrous resonance effects occur if the number of betatron cycles per orbital revolution becomes integral or half integral, resulting in loss of the particles to the walls of the vacuum chamber. The values of $n$, i.e. the strength of focusing, have therefore been reduced below the 5000–10 000 originally contemplated, in order to leave, as it were, more operating space between the resonances. Even at the values of a few hundred for $n$ at present envisaged at CERN and Brookhaven, for the 20–30 GeV machines, a considerable reduction of magnet aperture is still possible, with a corresponding saving in capital cost. There are many other problems, mostly concerned with the maintenance of particle stability, and both groups have been actively studying these, as well as engineering design, for about two years.

The orbit radii of these machines will be about 100 metres, and the particles will have to be constrained to move through an aperture about $7 \times 12$ cm during many thousands of orbits. Very close mechanical, magnetic, and timing tolerances will have to be achieved, but the total weight of steel in the magnet can be kept down to about 4000 tons for an energy of 25 GeV. This is only twice the weight of steel in the Cosmotron, which has a vacuum-chamber aperture of $91 \times 23$ cm.

The same method of alternating gradient focusing, but with zero field along one axis, has made it possible to be reasonably confident of success in attempting to focus the beam of a proton linear accelerator without serious loss of particles.

## Some Typical Experiments with High-energy Accelerators

### PROTON POLARIZATION

The discovery, at the University of Rochester in 1953, of polarization effects in the scattering of high-energy protons by nuclei, exemplified the element of the unexpected in scientific research. It had long been thought that polarization should occur in the scattering of nucleons by other single nucleons, as a result of non-central components of the nucleon-nucleon forces, and attempts were being made to obtain experimental evidence. Polarization may be detected in a 'double scattering' experiment, in which particles, scattered in a particular direction with respect to the primary beam, are passed through a second scattering device. If polarization effects are present, the beam emerging from this second device at a fixed angle with respect to the first-scattered beam will have a different intensity when scattered to the left as compared with the right. In a polarization experiment on proton-proton scattering, the bombarding particles would be protons, and ideally both scatterers would consist only of hydrogen. The use of hydrogen is inconvenient, however, and at Rochester the practice was adopted of using hydrocarbons, a subsequent experiment with pure carbon enabling the effect due to hydrogen to be distinguished. Polarization in proton-proton scattering was detected, but a considerably stronger polarization was discovered in the pure carbon. All elements which have been tried exhibit similar effects. The phenomenon has been found to be associated with the nucleus as a whole, and not with the individual nucleons, and the strongest polarization appears to occur in elastic collisions, i.e. those in which nuclear excitation or disintegration does not take place.

There has been great activity in this field during the past year, and results have been obtained at Rochester, Chicago, and Berkeley in the United States, and at Harwell in Britain. Figure 1 is a diagram of the experimental arrangement used at Harwell. Protons of maximum energy 160 MeV are allowed to strike a target $T_1$ in the vacuum chamber of the Harwell synchrocyclotron; those scattered through an angle of about 20°, and possessing an energy of 135 MeV, escape from the magnet through a magnetic shielding channel C. These first-scattered particles pass, in an evacuated tube, through a concrete shielding wall S and are collimated by slits. A second scattering takes place in the target $T_2$, and the second-scattered particles are detected in a system of counters D arranged as a 'telescope' and set at an angle $\theta$ with respect to the first-scattered beam. The primary beam, and the first- and second-scattered beams, are all arranged to be in the same plane. The detecting counters D may be rotated through 180°, about the first-scattered beam as an axis, into the position shown in dotted lines in figure 1. If there is polarization, the number of particles counted in these two positions, for a standard bombardment in each case, will be different. Elaborate checks are made, of course, to ensure that any effect observed is not attributable to errors in the alignment of the apparatus. The quantity determined is the 'asymmetry,' defined as

$$\epsilon = \frac{\mathcal{N}_1 - \mathcal{N}_2}{\mathcal{N}_1 + \mathcal{N}_2}$$



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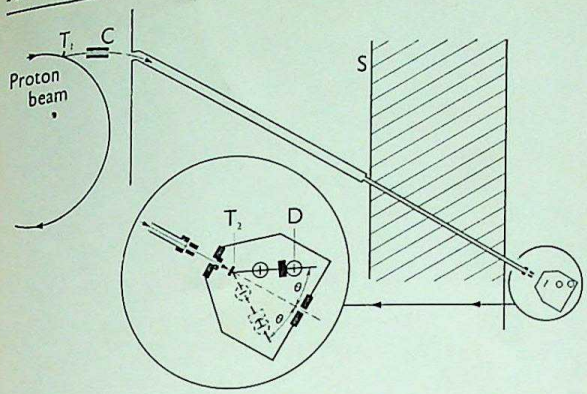


FIGURE 1 – *Plan of an experiment on the polarization of high-energy protons, using the Harwell synchrocyclotron.*

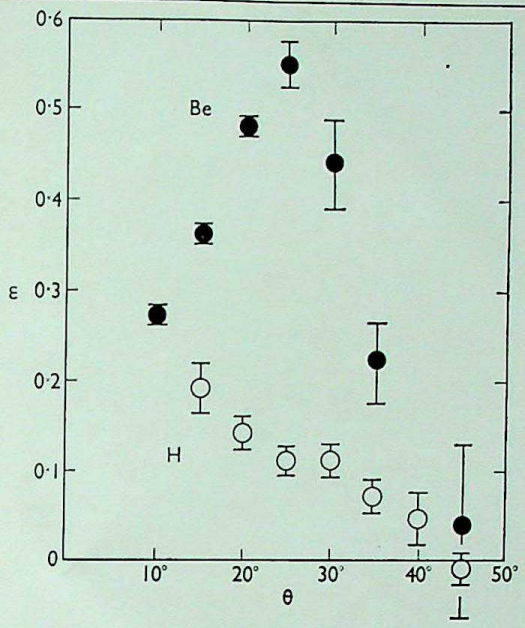


FIGURE 2 – *Variation of observed asymmetry ε with second scattering angle θ, in Harwell experiments on the polarization of high-energy protons.*

where $N_1$ is the number of particles scattered in the same direction as the first scattering (same azimuthal angle) and $N_2$ is the number of particles scattered in the opposite direction (azimuthal angle different by 180°).

The polarization at a particular angle can easily be calculated from the observed asymmetry, provided that one and the same process is known to be involved in each scattering and the two scattering angles are the same. Much of the experimental programme on this phenomenon has to be devoted to attempts to separate the different scattering processes which occur when high-energy protons strike a target. However, if a finite value of ε is obtained, then polarization is clearly taking place, and figure 2 shows the observed values of ε as a function of second-scattering angle in experiments at Harwell.

### OBSERVATION OF INDIVIDUAL PARTICLES

It is always necessary to use, in addition to counter techniques, methods of detection which display the tracks of individual particles for visual examination. These methods are very laborious when statistics comparable with those obtainable with counters are required, but are indispensable in the initial interpretation of many phenomena, particularly when 'new' particles are involved. Tracks may be made visible in cloud chambers and similar instruments, and in special photographic emulsions.

Two recent developments in the cloud chamber technique have greatly increased its effectiveness for use with accelerators. The original cloud chamber of C. T. R. Wilson produces supersaturation of a vapour-gas mixture by a controlled adiabatic expansion, and the tracks of ionizing particles are indicated by the formation of droplets on the ions. The tracks are photographed, usually by a stereoscopic camera so that the particle trajectories may be reproduced in three dimensions. Momentum measurements may be made if a magnetic field is applied during the passage of the particles through the chamber, and tracks may be observed resulting from nuclear collisions in the gas or vapour or in plates of solid material introduced into the chamber. Although this technique has been greatly developed, mainly by cosmic ray physicists, it is not very economical of the running-time of large accelerators, because the time required between expansions is greater than the normal interval between accelerator pulses. In the diffusion cloud chamber, first proposed by A. Langsdorf and developed in recent years mainly at Brookhaven, a gas may be continuously supersaturated with vapour by means of a thermal gradient on the walls of the containing vessel. This technique has been made to work very well with hydrogen, at about 20 atmospheres pressure, in vessels a few metres wide; a chamber of this kind is capable of receiving beam pulses at the full rate of about 10 per minute from a machine such as the Cosmotron. Hydrogen is, of course, a particularly important substance in studies of elementary nucleonic processes, and it is always important, when studying rare events, to be able to observe a particle traversing a great mass of material, so that the high pressure and large size of the chamber are important features. Figure 9



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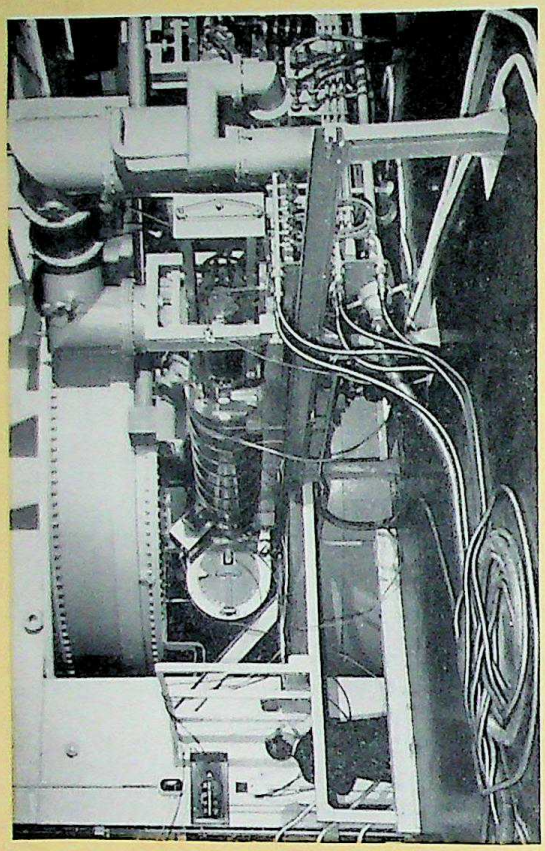

FIGURE 4 – *The* 110-*inch Harwell synchrocyclotron.*

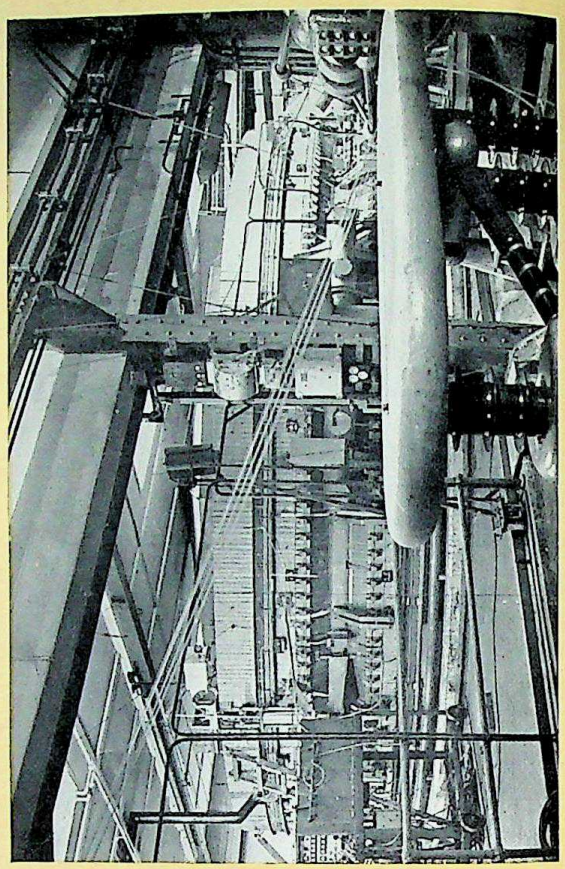

FIGURE 6 – *The Birmingham proton synchrotron.*

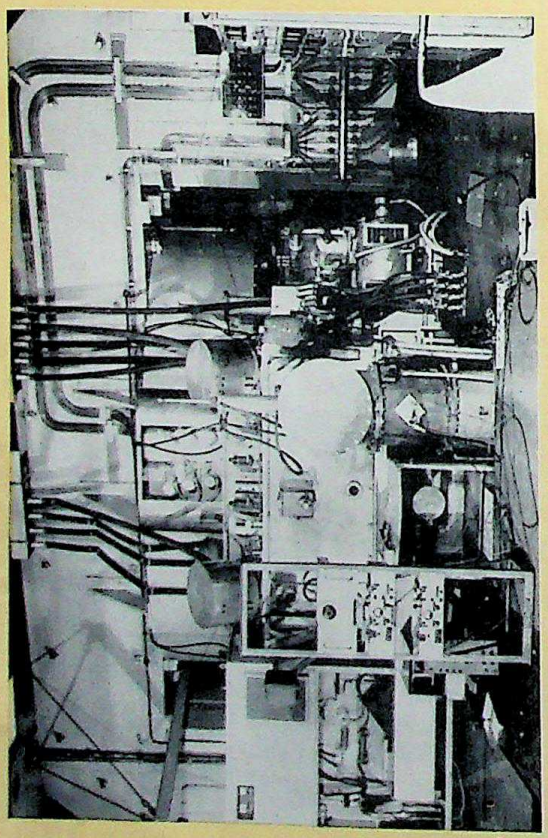

FIGURE 3 – *The* 156-*inch Liverpool synchrocyclotron.*

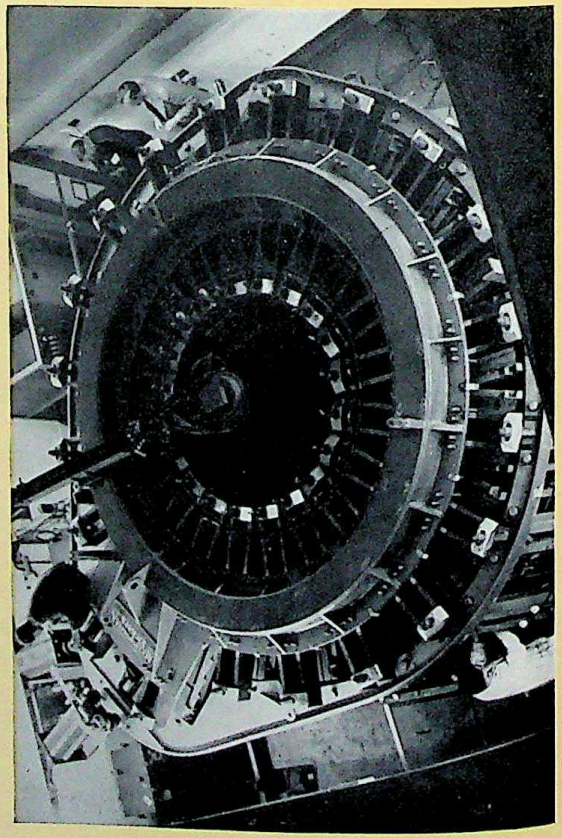

FIGURE 5 – *The Glasgow electron synchrotron.*



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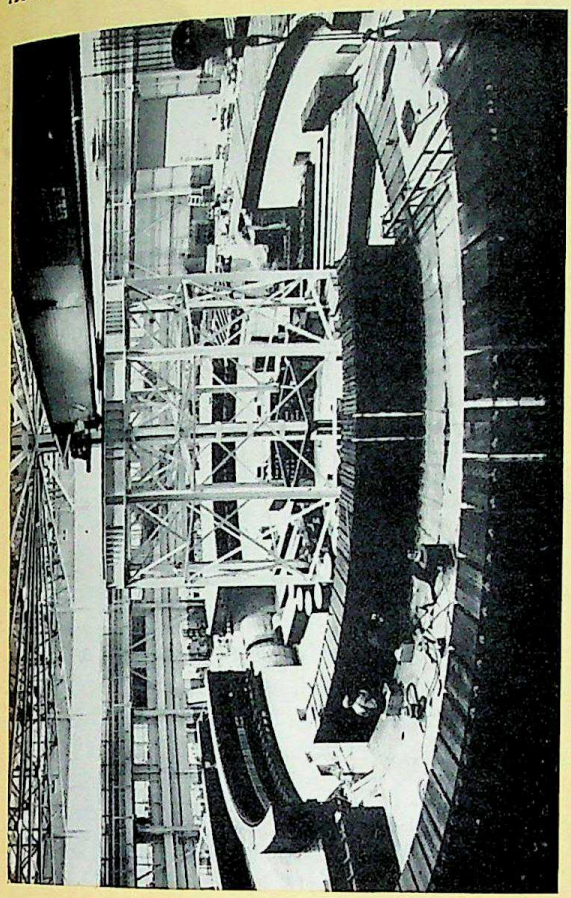

FIGURE 6 – *The Birmingham proton synchrotron.*

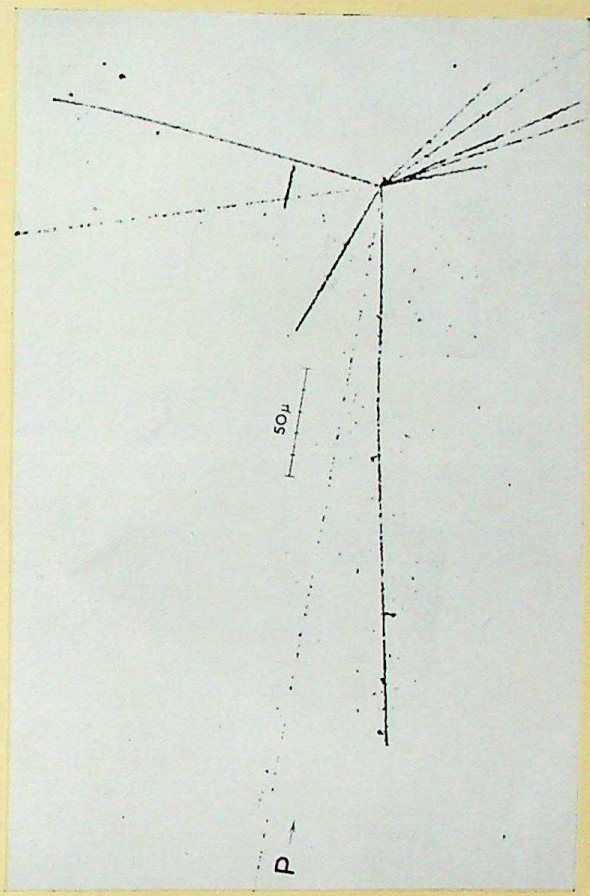


FIGURE 8 – *The Berkeley proton synchrotron (Bevatron), shown under construction.*

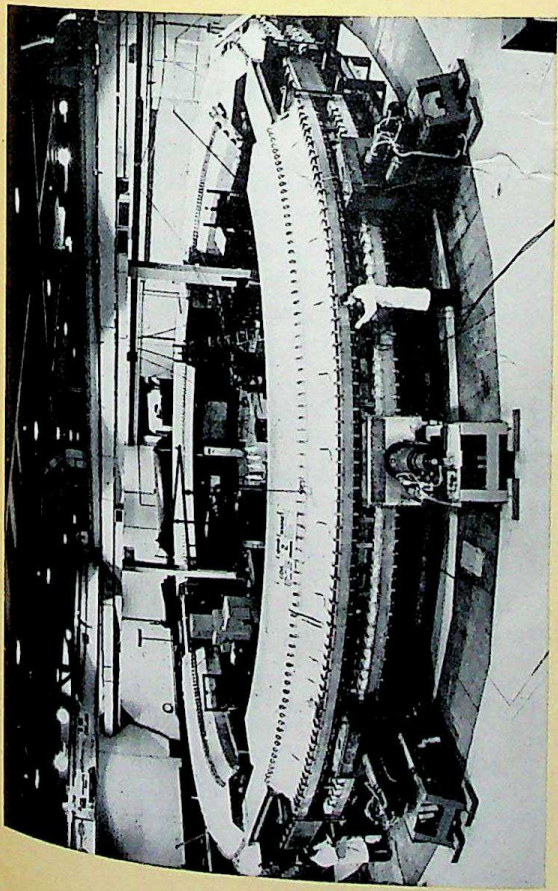

FIGURE 5 – *The Glasgow electron synchrotron.*

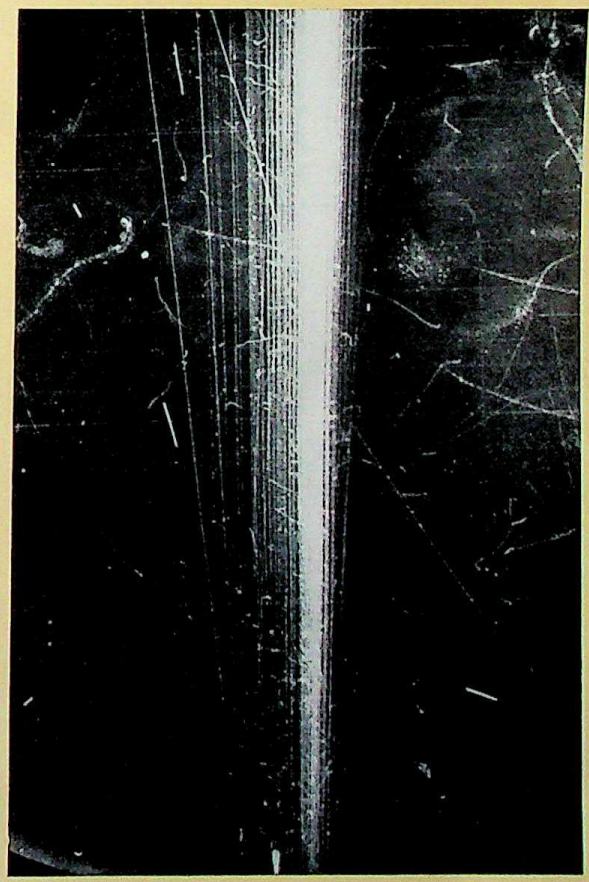

FIGURE 10 – *Nuclear disintegration caused by a 1 GeV proton. Tracks produced in a nuclear emulsion exposed to the beam of the Birmingham proton synchrotron.*



FIGURE 7 – *The Brookhaven proton synchrotron (Cosmotron).*



FIGURE 9 – *Tracks in a diffusion cloud chamber irradiated by 150 MeV protons from the Harwell synchrocyclotron.*



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is a photograph of tracks made in a diffusion cloud chamber by 150 MeV protons from the Harwell synchrocyclotron.

The second development in this field is a very recent one. Physicists at Brookhaven, Chicago, and Berkeley have developed the 'bubble chamber' technique, in which bubbles of vapour form along the track of an ionizing particle in a superheated liquid. The superheated condition is achieved by making a carefully controlled and timed reduction of pressure. Considerable success has been achieved with liquid pentane, and some success with liquid hydrogen. So far, the biggest chambers are only a few centimetres across, but the great density of the medium is an enormous advantage in work with high-energy particles.

The nuclear emulsion technique has the advantage of employing a medium of very high density, but the bulk of the material consists of silver and bromine, together with carbon, hydrogen, and oxygen, so that this method is less flexible. The modern development of the technique was pioneered by Powell's group at Bristol, for application both to cosmic ray research and to work with accelerators.

Figure 10 shows a 'star' observed in a nuclear emulsion exposed to the beam of the Birmingham proton synchrotron. A nucleus in the material of the emulsion has been highly excited by the impact of the energetic primary particle (a 1 GeV proton), and the energy of excitation was sufficient to disrupt the nucleus into several fragments, which moved away with considerable velocity. The nine charged fragments left tracks visible under the microscope after development of the emulsion. Uncharged particles leave no record in the emulsion, but some would undoubtedly be produced in a disintegration of this magnitude.

The Cosmotron group at Brookhaven has been able to demonstrate the artificial production of some of the new particles identified in cosmic rays, using both cloud chamber and emulsion techniques. They have observed many cases of $\Lambda^0$ and $\theta^0$ particles in the diffusion cloud chamber, and some of their photographs show the decay products of one of each of these particles, presumably produced in the same event. $\Lambda^0$ particles have a mass somewhat greater than that of the proton, are uncharged, and decay into a proton and a negative $\pi$-meson. $\theta^0$ particles have a mass about 1000 times the electron mass, are also uncharged, and decay into a positive and a negative $\pi$-meson. The double events were observed when the hydrogen-filled diffusion chamber was exposed to a 1·5 GeV negative $\pi$-meson beam emerging from a target bombarded by protons in the Cosmotron. The following reaction is presumed to have occurred:

$$\pi^- + p \rightarrow \Lambda^0 + \theta^0$$
$$\Lambda^0 \rightarrow p + \pi^-, \quad \theta^0 \rightarrow \pi^+ + \pi^-$$

The four decay-product particles are identifiable from studies of the photographs.

There is a large class of 'heavy mesons' discovered in cosmic ray research and known collectively as K-mesons. The $\theta^0$ particle is an uncharged member of this family, but there are believed to be several charged varieties with masses about 1000 times the electron mass. Several kinds of charged K-mesons have already been observed in studies of nuclear emulsions exposed to the beam of the Cosmotron.

The situation with regard to these newly discovered particles is very complex, but it is certain that knowledge of their properties and the conditions under which they may be produced will rapidly expand as work proceeds on the large accelerators. All the unstable particles so far known have been discovered in studies of cosmic rays, with the exception of the $\pi^0$ meson (which was very nearly discovered by Powell's group!), but the more intense beams produced by accelerators have proved to be essential in studying the production and properties of mesons and their interaction with other particles. In this sense cosmic ray research and accelerator research have been truly complementary.

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# Determination of the absolute configuration of optical antipodes

J. M. BIJVOET

Optical antipodes have atomic arrangements that are the inverted images of each other. Although the nature of atomic arrangements can be determined in all minor details, the problem of which of the two possible configurations corresponds to a particular compound long remained unsolved. X-ray analysis, however, has now provided a means of establishing this 'absolute' configuration, although it at first seemed incapable of doing so.

The relative positions of the atoms in a large organic molecule can be determined in two entirely different ways. The chemical method involves the determination of the atomic arrangement by breaking the molecule into smaller fragments, the structures of each of which have already been established by similar means. The determination by this method of the atomic pattern of hundreds of thousands of compounds, from very simple ones to complicated alkaloids and hormones, is one of the major achievements of science. Van 't Hoff's concept of the tetrahedral carbon atom made possible the extension of structural formulae to include spatial configuration.

The second, non-destructive, method of determining atomic order is X-ray analysis. The gas or crystal is exposed to a beam of X-rays, and the resulting diffraction pattern is recorded. Each atom causes uniform scattering of the incident rays in all directions, and the waves scattered by the different atoms of a molecule or a crystal interfere. For each direction of diffraction the waves originating from the various atoms have path (phase) differences. These path differences determine the effect of the interaction of the various waves and the resultant intensity in each direction. As these path differences depend, in turn, on the magnitude and orientation of interatomic distances, it is possible to calculate the atomic configuration from the diffraction intensities forming the X-ray pattern.

It is gratifying to find that these two entirely different methods lead to essentially the same results. X-ray analysis leads to a scaled and geometrically exact structural model, in which the interatomic distances may be indicated with an accuracy of a hundredth of an Angstrom. Unlike chemical determination methods, X-ray diffraction permits the study, under favourable conditions, of an arbitrarily chosen compound, without need of any knowledge of allied substances. When, for example, Gammexane, one of the stereo-isomers of benzene hexachloride, was found to possess insecticidal action, attention was suddenly focused on its configuration, which X-ray analysis determined directly, as opposed to its molecular structure. On the other hand, determination of the structure by chemical methods, which has also recently been achieved, required a fairly extensive study of the various stereo-isomers, and of a number of hepta- and octa-chlorocyclohexanes.

As molecular structure can be established in minute detail, by either chemical or X-ray methods, it is surprising to find that neither method was able to provide an answer to the question which is discussed in the present article.

It is common knowledge that there are compounds whose crystals, or even molecules in solution, rotate the plane of polarization of light. These compounds occur in two forms, which are distinguished by the fact that one rotates the plane of polarization to the right (positive rotation), and the other to the left (negative rotation). In denoting these optical antipodes the name is accordingly prefixed by (+) or (−) respectively. Classical examples are (+) tartaric acid and (−) tartaric acid; (+) quartz and (−) quartz. Neither the crystals nor the molecules of these optical isomers are superimposable; they are mirror images of each other. An example of this is shown in figure 1, where the left-hand model is denoted by D, the second by L.

As we have seen, it is possible to determine the molecular structure of all optically active compounds, but surprisingly enough we cannot state which of these two models, D or L, corresponds to the dextrorotatory antipode and which to the laevorotatory one. Before discussing how this



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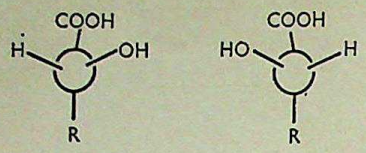


FIGURE 1 – *α-substituted acids are conventionally given the prefix D if the α-substituted group points to the right when the —COOH group is at the top and —COOH and —R point backwards.*

problem may be solved it is appropriate to discuss the factors which create it.

### CHEMISTRY AND ABSOLUTE CONFIGURATION

Chemistry determines the relative behaviour of compounds, i.e. the relationships between different structures. Consequently, it is not possible to detect by chemical means the changes that would occur if all optical antipodes assumed or possessed their inverted configurations. It is possible, however, to determine the relative configurations of allied optically active compounds. Thus we can ascertain whether, for instance, (+) lactic acid ($CH_3CHOH\ COOH$) corresponds, in the configuration of its four groups round the asymmetric carbon atom, to (−) or to (+) alanine ($CH_3CHNH_2COOH$).

It appears that direct substitution of —OH or —$NH_2$ at the asymmetric atom may be accompanied by inversion of the configuration (Walden inversion). The generic relation does not, therefore, lead to a decisive conclusion regarding the relative configuration. A way of determining the latter is to effect in each of the two compounds the same chemical change in one of the substituents bound to the asymmetric carbon atom.

Such a substitution may be expected, for corresponding configurations, to bring about analogous changes of the rotation. Table I shows that in fact (+) alanine has the same configuration as (+) lactic acid. Thus a relationship is established between the configurations of the amino acids and of the oxy-acids.[1]

TABLE I

| *Derivative* | (+) *lactic acid* | (+) *alanine* | (−) *alanine* |
|---|---|---|---|
| Amide of the benzoyl compound | + 120° | + 70° | − 70° |
| Ethyl ester of the benzoyl compound | + 49° | + 12° | − 12° |
| Methyl ester of the benzoyl compound | + 35° | + 4° | − 4° |
| Ethyl ester of the acetyl compound | − 76° | − 74° | + 74° |
| Ethyl ester of the toluene sulphonyl compound | − 129° | − 78° | + 78° |

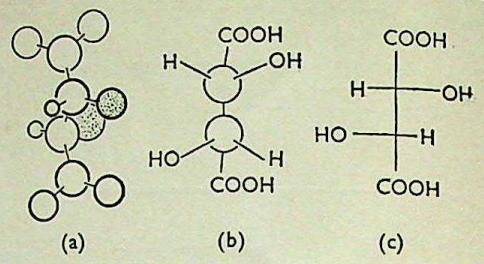


FIGURE 2 – *Absolute configuration of natural dextrorotatory tartaric acid.* (a) *As determined by X-rays in sodium rubidium tartrate.* (b) *In normalized configuration, by rotating around single bonds.* (c) *In projection.*

It is generally known that these relative configurations are of the utmost importance to the course of reaction between optically active compounds. In order to facilitate expression of these relationships Emil Fischer arbitrarily assigned the configuration of figure 2(*b*) to one substance, viz. to natural dextrorotatory tartaric acid. There is an even chance that this choice represents the true situation.

It may be true that only the relative configurations, and not the right choice of the absolute ones, are of vital importance to chemistry. Yet the advantages of knowing the absolute configuration are not limited to the mere satisfaction of knowing, nor to a didactic simplification resulting if reality, instead of arbitrary convention, can serve for assigning structures and as a basis of nomenclature. A direct method of determining absolute configuration has practical importance for establishing or confirming relative configurations in cases where chemical methods present difficulties. As an example of these difficulties we may again mention the uncertainty whether substitution of one of the groups about an asymmetric carbon atom causes the configuration to be inverted or not.

### OPTICAL ROTATION AND ABSOLUTE CONFIGURATION

An obvious physical method for determining absolute configuration is the theoretical calculation of the rotation of the plane of polarization of

[1] A direct method for relating two compounds from different optically active series is to incorporate their asymmetric atoms into one molecule. It has, for instance, been demonstrated—X-ray analysis leaves no doubt whatever in this respect—that the —OH and —COOH groups in hydroxyproline are in the *trans* position. This, again, establishes the relationship between α-oxy- and α-amino acids.



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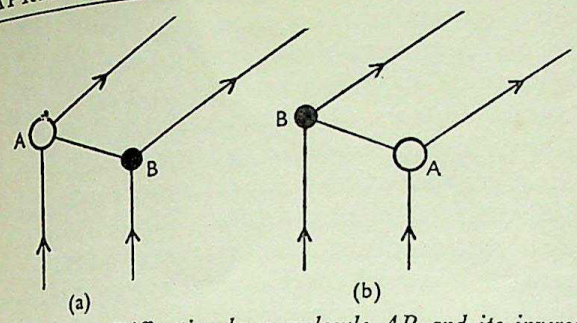


FIGURE 3 – *Diffraction by a molecule AB and its inverse configuration BA respectively.*

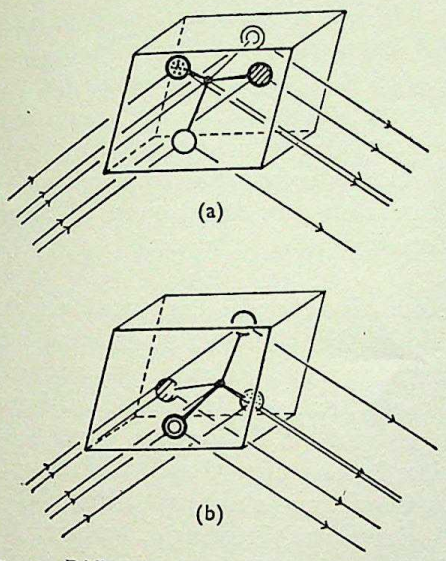


FIGURE 4 – *Diffraction by asymmetric molecule. Cf. figure 1.*

polarized light.[1] Starting from one of the mirror images, it is computed whether this configuration should give laevo- or dextro-rotation. A number of workers, especially during the years 1935–40, made calculations of optical activity on the basis of a number of theories (Kuhn [1], Eyring [2]). However, there being no sufficiently clear picture of the details of the atomic structure, there was no agreement between the results. Work carried out in this period on particular molecules, for example methylethylcarbinol, led to results that even differed in sign [3].

In the last few years interesting calculations have been carried out—including calculations with two or more related compounds—which can probably be considered reliable (Kirkwood, Looyenga, [4]). In agreement with Kuhn's result, they confirm Fischer's arbitrary convention as representing, in fact, the true situation.

Crystals, as well as liquids, have been the subject of computations. It seems reasonable to suppose that a pronounced right-handed spiral structure in the crystal corresponds to a rotation to the right, looking in the direction of propagation of the light (Wooster [5]).

### NORMAL X-RAY DIFFRACTION AND ABSOLUTE CONFIGURATION

The essential difficulty in the X-ray determination of the absolute configuration is explained in figures 3–5. Figure 3(*a*) shows the diffraction of an X-ray beam caused by a molecule AB, and 3(*b*) the diffraction caused by its inverted configuration BA, where only the sense of the direction of the line BA has changed.

While in the situation indicated in figure 3(*a*) the rays diffracted by atom A have the smaller path length, in figure 3(*b*) they have the longer path. However, as regards its absolute value, the difference in path length between rays diffracted by A and B is seen to remain unchanged. This causes the resultant intensity to remain unchanged. As this holds good for any direction of diffraction, the two situations are indistinguishable by simple X-ray analysis.

It holds good, too, for inversion of any structure. A structure is inverted by connecting each of its points P with an arbitrarily chosen centre O and by extending line PO by its own length to P′. All points P′ together give the inverted image. Just as in figure 3, the line connecting two points then changes only in sense. Hence, on inversion of a structure the phase difference involved in the interference is exactly inverted for each pair of atoms; consequently their contribution to the interference, and therefore to the diffraction intensity, remains unchanged.

A certain set of intensities may thus be caused either by a structure A or by the inverse structure A′. X-ray analysis cannot therefore distinguish inverse structures. In the case of optical antipodes the inverse structure, as is shown by figure 5, is the other antipode in a related orientation; therefore X-ray analysis cannot distinguish optical antipodes.

### ANOMALOUS DIFFRACTION

It is curious to note that an assumption introduced here was discussed in the early days of X-ray analysis and found to be not universally

[1] Another obvious method is to ascertain whether the face development in the crystal of an antipode is more consistent with one configuration than with the other. However, such a derivation from the growth-rate of crystal planes is extremely difficult and has not led to a reliable conclusion.



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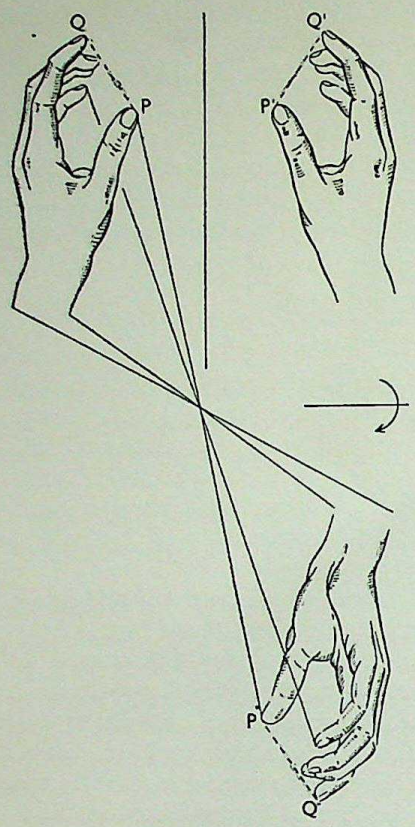


FIGURE 5 – *Inversion is equivalent to reflection combined with rotation through* 180° *about an axis normal to the reflection plane. This results in formation of the opposite antipode.*

valid. The assumption is that the phase difference between the waves originating from two atoms '*nur von dem Unterschiede des durchlaufenen Weges abhängt und dass die Natur des Atoms auf die Phase keinen Einfluss hat*' ('depends only on the path difference and that the nature of the atoms has no influence on the phase') (W. L. Bragg [6]). The question is whether or not a phase shift occurs at the diffracting atom (or may occur under special conditions), between incident and emitted radiation, and to what extent this phase shift, which is equivalent to an apparent reduction of the real path-length, may affect the above considerations. In the mutual phase differences between the waves diffracted by the various atoms this phase shift is, of course, neutralized as long as it is equally great for all these atoms, i.e. as long as '*die Natur des Atoms auf die Phase keinen Einfluss hat.*' However, although the latter appears to be the rule under 'normal' conditions, it is not universally true.

It is the electrons in an atom that the incident X-rays cause to vibrate and to radiate. As long as the electrons can be considered to be weakly bound, they vibrate in opposite phase to the incident rays.[1] Only in heavy atoms do the strongly bound electrons of the inner shell (K electrons) vibrate in phase with the incident wave.[2] Such an exact counteraction within the atom between the diffraction of K electrons and that of the other electrons does not alter our argument in any respect; it only changes to some extent the magnitude of the diffracting power of the atom.

As far back as 1916 Von Laue [7] wrote: '*Es wäre eine interessante Frage für den Versuch, ob sich nicht, namentlich bei stark absorbierenden Kristallen, und wenn die Frequenz der einfallenden Strahlung nahe einer Eigenfrequenz des Atoms liegt, doch Ausnahmen feststellen lassen.* ('It would be an interesting subject for experiment, in particular for strongly absorbing crystals, to see whether an exception could be established in cases where the frequency of the incident radiation lies near a natural frequency of the atoms.')

The situation may be elucidated with the aid of an analogy. Let there be a pendulum which, by coupling, imparts its vibration to another (figure 6). If the latter has a lower natural frequency—longer pendulum B, weaker 'bond'—it starts vibrating in opposite phase. If it has a higher natural frequency—shorter pendulum C, stronger 'bond'—it starts vibrating in phase. There is therefore complete analogy with X-ray vibration, represented by A, causing a weakly or a strongly bound electron to resonate.

Let us suppose that the exciting vibration, starting from a high frequency, decreases in frequency. In the case of the pendulum the imparted vibration undergoes the phase shift of 180° exactly at the point where the frequency of the incident vibration corresponds with the natural frequency of the pendulum. In the case of the atom the situation is slightly different. Here, too, incident radiation of high frequency causes all electrons to vibrate in phase opposite to that of the incident rays. If the frequency of the latter decreases, it approaches the range of natural frequencies of the K electrons. However, in an atom the electrons are not bound by any one frequency, but the binding of the K electrons is characterized by the range of frequencies that may excite these electrons and shift them to available orbits. If the

[1] This is because the acceleration will be in phase with the electric force, but the acceleration and deflection of a vibration are in opposite phase.

[2] This is because here the electric force must, at any given moment, essentially compensate the binding force.



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frequency of the X-ray beam falling upon the atom approaches and passes through this absorption zone, it was expected—and was later confirmed by quantum-mechanical calculations—that the phase of the co-vibrating K electron will change gradually.

It is these phase shifts at the diffracting atom, deviating from π or zero and referred to by Von Laue, that permit determination of absolute configuration by X-ray analysis.

### ANOMALOUS DIFFRACTION AND FRIEDEL'S LAW

Not until 1930 was the test suggested by Von Laue actually carried out. It was done to check the so-called Friedel's law, which expresses the equivalence of reflection and counter-reflection, i.e. the effect at the diametrically opposed sides of a crystal (figure 7). Their equivalence follows naturally from considerations of symmetry if, as in figure 7(*b*), there is no difference in the succession of the planes from below upwards or from above downwards. In the case of a polar succession, as in figure 7(*a*), there is, however, no consideration of symmetry that precludes a non-equivalence of reflection A and counter-reflection A′.

It is true that Friedel was initially of the opinion that '*les deux rayons A et A′, identiques par symétrie dans le cas de l'holoédrie, restent forcément identiques par symétrie dans le cas de l'hémiédrie*', ('the two rays A and A′, identical by symmetry in the case of holohedrism, necessarily remain identical

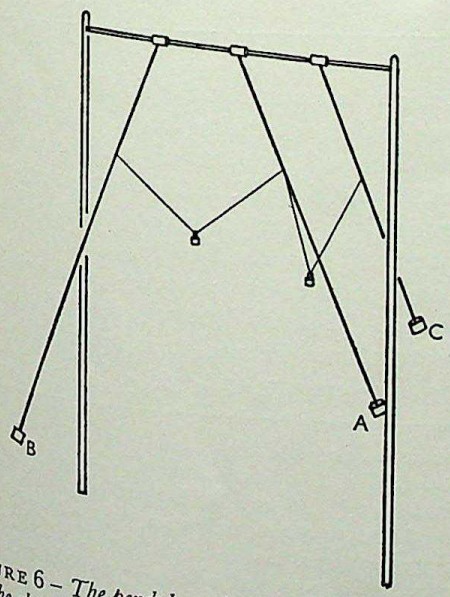


FIGURE 6 – *The pendulum A excites the longer pendulum B and the shorter pendulum C. B oscillates with opposite phase, C in phase.*

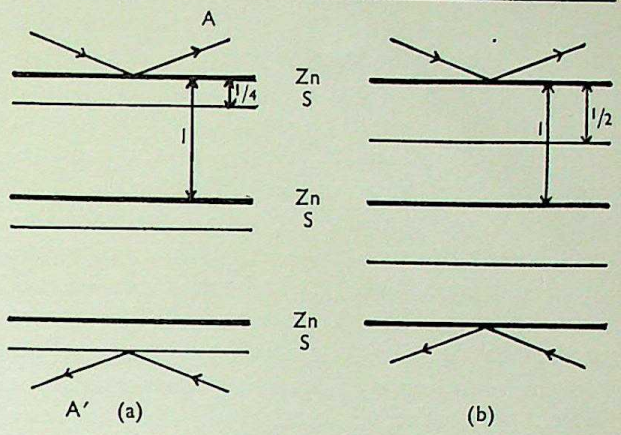


FIGURE 7 – *Reflection and counter-reflection from a polar* (a), *and a non-polar* (b), *succession of crystal planes.*

by symmetry in the case of hemihedrism'), but it was soon demonstrated that this '*forcément*' was not well founded.

Coster, Knol, and Prins [8] measured the intensity of reflections A and A′ for such a case as that shown in figure 7(*a*), which depicts a zinc blende crystal with tetrahedral planes alternately filled with Zn and S atoms. The distances between successive Zn and S planes is one-quarter of the period ZnS—ZnS. . . . In the so-called first-order reflection the path difference between the rays reflected by successive zinc planes is λ, and that between rays reflected by successive Zn and S planes is therefore λ/4.

For radiation of arbitrary wavelength the difference in phase shift is the same at the zinc atom as at the sulphur atom. Consequently, with reflection A the wave reflected by the zinc plane leads the wave reflected by the sulphur plane by 90°, whereas with reflection A′ it lags 90° behind. Composition of the two waves gives the same resultant intensity, in spite of the polar succession which, again, causes only the sign of the phase difference to change. Normal X-ray reflection does not detect any difference between one side, a dull and poorly developed tetrahedron plane, and the other, a shining and well-developed one. In this respect it is less sensitive than the human eye.

Coster, however, chose a radiation—$L\alpha_1$ radiation of gold—which just excites the K electrons of zinc. In this anomalous scattering the phase at a zinc atom gets a lead when compared with the wave at a sulphur atom. Let us suppose the magnitude of this lead to be 10°; this is about the value that can be expected theoretically.

For reflection A the total phase difference that is active in the interference is then 90° + 10° = 100°, instead of 90°. For the reflection B it is



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$-90° + 10° = -80°$. The combination has therefore been shifted in the direction of counteraction (180°) in A, but in the direction of reinforcement (0°) in A′. A must therefore have a lower intensity than A′. Coster *et al.* have succeeded in demonstrating this difference.

Now X-ray analysis not only detects a difference, but it concludes—and this is, of course completely impossible for the human eye—that it is the dull plane that has the Zn side facing outwards: for the dull plane is found to give the weakest reflection and, as has been argued, the weakest reflection is that from the Zn-plane (figure 7(*a*)).

Friedel's law being shown not to hold good, it is possible to determine whether the crystal is being viewed in the ZnS—ZnS direction or in the SZn—SZn direction. This can be generally expressed by saying that the polarity of an atomic succession can be determined with the aid of anomalous diffraction.

As has been stated above, in normal diffraction X-rays do not detect any difference between right-hand and left-hand antipodes. In this respect they are inferior to the human eye. It will be shown, however, that anomalous diffraction is even capable also of assigning to them their absolute configuration.

### ANOMALOUS DIFFRACTION AND ABSOLUTE CONFIGURATION

From 1930 to 1950 knowledge that Friedel's law does not hold good in the case of anomalous diffraction went side by side with the idea that it was fundamentally impossible to determine absolute configuration by means of X-ray analysis. However, figure 8, (*a*) and (*b*), shows the identity of this problem with that of figure 7(*a*). In both cases a polar succession of atomic planes is involved, and it is the sense of this succession which must be determined.

Whether or not a structure is involved which, on inversion, is superimposable on itself—ZnS case and identification of antipodes respectively—is irrelevant. If the antipodes are in inverted positions the reflections become unequal in intensity—and the structures become distinguishable—if in the phase difference between two atoms,

$$(\varphi_B - \varphi_A)_{total} = (\varphi_B - \varphi_A)_{path\ difference} + (\varphi_B - \varphi_A)_{primary\ diffraction\ process},$$

the last term is not zero (anomalous diffraction). Consequently, the total phase difference does not merely change its sign when the path differences do so.

Let us imagine that a normal structure determination of an optically active compound has been performed; it results in the structure being defined except for possible inversion. Calculation will show for which of the two (dextro or laevo) configurations the intensity of a certain reflection will increase, and for which it will decrease, when a radiation is used that just excites one of the atoms. Measurements of this anomalous reflection for the two antipodes[1] then make unambiguous assignment of configuration possible.

TABLE II

*Calculated intensities of normal and anomalous diffraction (RbH tartrate)*

| *Indices of reflection plane* | *Calculated intensities* | | |
|---|---|---|---|
| | *D-model anomalous diffraction* | *Normal diffraction* | *L-model anomalous diffraction* |
| 113 | 281 | 313 | 351 |
| 114 | 412 | 385 | 369 |
| 123 | 371 | 420 | 482 |
| 124 | 226 | 217 | 212 |
| 125 | 63 | 55 | 52 |
| 126 | 159 | 152 | 147 |
| 135 | 227 | 250 | 278 |
| 141 | 239 | 223 | 209 |
| 143 | 188 | 165 | 149 |
| 146 | 80 | 82 | 93 |
| 151 | 359 | 333 | 316 |

It is curious to note that the significance of the ZnS case for the determination of absolute configuration became apparent only when it revealed itself most strikingly, viz. in the Fourier synthesis of an optically active compound. The mirror images here differ in the location of the maxima of the density waves on one side of the origin or on the other. This ambiguity in the sequence of the density planes immediately reminds one of that shown in figure 7(*a*).

[1] It is easily understood that the intensity of a reflection remains unchanged if both structure and direction of X-rays are inverted ($I_b = I_c$, figure 8). Instead of comparing the same reflection at the two antipodes (figure 8a → b) one really compares the anomalous intensities of reflection and counter-reflection at one antipode (a → c). Not only does this measurement require only one antipode, but it is also more accurate because it is done with the aid of one crystal on one film.



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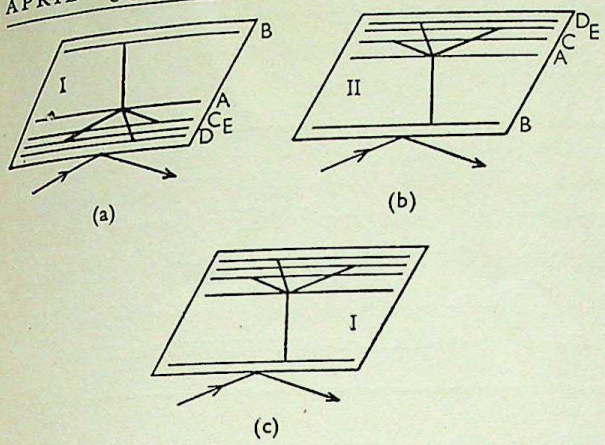


FIGURE 8 – (a) *and* (b) *are as in figure* 4; *through each atom a plane has been drawn parallel to the reflecting plane. In* (b) *the order of the planes DECAB is inverted with respect to* (a); (c) *is the counter-reflection of* (a).

Table II shows the effect of anomalous diffraction in the case of sodium rubidium tartrate dihydrate ($NaRbC_4H_4O_6.2H_2O$), in which the Rb atom was excited by ZrK radiation.

Table III shows the compounds whose absolute configurations have so far been determined. The characteristic radiation was obtained by means of a tube with a special anode (Zr, U). Recently, however, radiation of the desired wavelength has been obtained from the continuous radiation of a normal X-ray tube (Grenville-Wells and Lonsdale [10]); the reflecting plane is made to select the desired wavelength. This makes it possible to approach the absorption limit of any atom as closely as we like.

TABLE III

| *Compound* | *Excited atom* | *Radiation used* |
|---|---|---|
| NaRb tartrate 2 aq. [11] .. | Rb | ZrKα |
| RbH tartrate [12] .. .. | Rb | ZrKα |
| *iso*leucine HBr 2 aq. [13] .. | Br | UL |
| $2[CoEn_3]Cl_3.NaCl.6H_2O$ [14] .. | Co | CuKα |

Dextrorotatory tartaric acid thus appears to possess the configuration of figure 2, so Fischer's arbitrary convention is proved to correspond with reality.

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# The colour changes of cephalopods

WILLIAM HOLMES

The striking colours, and amazingly rapid colour changes, shown by cephalopod molluscs are little known, though in many ways they are more beautiful than the familiar forms of animal coloration. The biologist certainly regards them as unique, for the mechanism behind the colour change is found in no other group of the animal kingdom. As many of the colour patterns are of extremely brief duration, much interest attaches to the accompanying illustrations.

The cephalopods are so called because they have developed long 'limbs' near the mouth, a feature which is among those distinguishing them from lower molluscs, such as snails. The octopod molluscs (e.g. *Octopus*) use these structures both as arms in feeding, and as legs in locomotion. The decapods (e.g. *Sepia*, the cuttlefish, and *Loligo*, the squid) use them as arms only, and move themselves about either by the undulations of a fin which runs down either side of the body or by the expulsion of a jet of water from one of the body-cavities.

The most primitive molluscs undoubtedly had a shell, which is a protection against many sorts of predator. But a shell is a cumbersome thing, restricting activity, and the evolution of the group involved exploring new food sources inaccessible to an animal with a heavy shell. Accordingly the cephalopods developed the arms and the jet-propulsion mechanism; at the same time they gave up the shell as a protection. In decapods the shell remains only as the 'cuttle-bone,' lying below the skin; this gives little protection, for it does not cover the head.

The power of changing colour is a new, alternative, protective device, and since it was acquired by molluscs late in their evolution it is not surprising that it is brought about by a unique mechanism. Other animals use colour and colour change as a means of stimulating, deceiving, or frightening each other or their predators or their prey, but the underlying processes are different.

Sometimes the body of a recently dead cuttlefish or squid is found on the sea-shore; even if it has been dead for some hours the chromatophore activities which are the basis of colour change may still be seen taking place: waves or clouds of colour pass over the surface of the body, changing continuously and in a matter of seconds. The waves of colour show variations on black, brown, red, and yellow. The general effect is the result of the activity of large numbers of individual coloured bodies in the skin—red, brown, or orange-yellow—on a background of pearly, iridescent white. Each of these bodies varies in size from an almost invisible pinpoint to a maximum which depends upon the species, but is as big as a pin's head or larger.

The chromatophores have been studied for many years, and it has long been known that each is a hollow sac with elastic walls, containing pigment granules; the chemical composition of these is still not known with certainty. Connecting the outer wall of the sac with the adjacent tissues are fibres of unstriped muscle radiating outwards in the plane of the surface of the body. Contraction of the fibres pulls the sac outwards into a flat disk, spreading its coloured contents over a wide area; when contraction of the fibres ceases, the elasticity of the sac reduces it again to a pin-point sphere [6]. Many studies have been made of the physiological properties of these minute muscle fibres. The rate of expansion of a chromatophore may be measured photo-electrically; the change from complete contraction to full expansion can occur in two-thirds of a second. The muscle fibres seem immune to fatigue, for their response is undiminished after effective stimulation for thirty minutes at a frequency of thirty shocks per second [4].

The chromatophores lie in three layers in the skin, the yellowish ones on top, the red in the middle, and the brown or black below [6]; they overlap each other when expanded, and consequently various compound colour effects result. The pearly background colour is the result of reflection of light from a layer containing structures of a different character, called iridocytes [7]. These are incapable of changing shape, but on certain areas of the body they are aggregated into clumps, which shine clear white; these, as we shall see, play a part, with the chromatophores, in the formation of colour patterns. Some of the clumps of iridocytes are, in a sense, mobile, for the



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skin containing them may either lie flat along the body or be arched up into conspicuous papillae.

### PROTECTIVE COLORATION

Animal colours can be classified into several categories according to their adaptive value; that is, according to the way in which they affect other animals of the same species, or animals of a different species in the same environment. Thus, its colour may cause an animal to resemble features of its immediate environment, rendering it more or less invisible to its enemies, who cannot distinguish it from other adjacent, inedible objects. Resemblance to its surroundings is equally valuable to an animal which is a predator, for then it can steal upon its prey unobserved. Again, we may have warning coloration: an individual may be equipped with bright colours, or colours arranged in striking patterns which are associated with effective weapons of defence or the ultimate protection of nauseous taste, or inedibility. By this last device the predator is trained to avoid other members of the race, though the individual is sacrificed. Another use of colour is that associated with the breeding habits of the animal, in which a particular play of colour, or a particular pattern, affects members of the opposite sex of the species, or competing members of the same sex.

The demonstration that the colours of a particular animal have a biological significance in any of these ways requires experiments on behaviour in which the animal itself, and its predators, prey, or mates are concerned. These are often difficult to devise, and since of all cephalopods the octopus is the only one which will live happily in an aquarium, information on this group is particularly meagre. Thus we have little certain knowledge of what animals are the chief predators of the cuttlefish; the remains of cephalopods occasionally found in the stomachs of fish or crustaceans may be of meals taken from dead or dying animals, and in consequence irrelevant to the problem of the normal predator. Scattered observations, made by naturalists over more than a century, leave the impression that it is mainly the aquatic mammals, such as dolphins and porpoises, that eat the active cuttlefish as a regular part of their diet. In the absence of experimental evidence we are bound to fall back on human judgment of the protective and warning significance of colour patterns, but we can also take into account evidence derived from more accessible examples of the phenomena associated with coloration, as in butterflies, reptiles, and birds. Fortunately, we have, from direct observations of mating behaviour [1, 8], more direct evidence of the sexual function of colour in cephalopods.

### COLOUR PATTERNS OF THE CUTTLEFISH

A cuttlefish swimming undisturbed in a large aquarium shows a 'zebra' pattern. Down both sides of its back run broad stripes, alternately dark brown and almost white (figure 5); similar stripes appear over the large lateral arms, one of which can be seen from the side in the same figure. It can also be seen that the fin, which was in motion, has a pale brown mottling, and that the underside of the body is white. In the black stripes the dark chromatophores are almost fully expanded; in the pale areas they are fully contracted. The pale areas vary in colour from orange to white, according to the degree of expansion of the lighter-coloured chromatophores; the purest white is seen when the light is almost all reflected from the iridocytes beneath. An area in the middle of the back, shaped like the cuttle-bone and lying over it, is mottled in colour when the animal is in a small tank which obliges it to be always near the bottom or sides. In a large tank, the zebra stripes pass over the whole of the dorsal surface, though they are narrower over the cuttle-bone. Figure 5 shows also that white circular areas, at the base of the fin, are an element in the pattern.

The ventral surface of the body is pale, and this difference between upper and lower surfaces demonstrates the first principle of protective coloration: that of 'obliterative countershading'. The dorsal surface receives most incident light, and reflects least; the ventral surface is in the shadow, and reflects almost all the light that falls upon it. This counteracts the normal effects of light and shade, which give the appearance of solidity to a body; thus the animal is protected by an artificial vagueness given to its form. If a cuttlefish is turned upon its back, as it must often be when fighting, the dark chromatophores of the ventral surface instantly expand, and so minimise the dangerous conspicuousness which would otherwise arise when the light fell on its white belly. The protective value of the black and white stripes needs no emphasis; these serve, as they do for the Zebra, to disrupt the shape of the body, and so to make it inconspicuous. The cuttlefish often swims among beds of waving seaweed, and when near the surface ripples of light and shade fall on it, adding to the deception.

Another environment in which cuttlefish are often found is shallow coastal water where the sea-floor



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is sandy or composed of shell gravel. When swimming close to such a bed the animal modifies its stripe pattern by a partial contraction of the dark chromatophores and further expansion of those of lighter shade. Thus it comes to match its background, having much less contrasted stripes, of a sandy colour, on its back, resembling the play of light on the sandy sea-bed. If it settles down on the sand the stripes disappear altogether, leaving a mottled pattern of an appropriate matching colour, resulting from reflection of light from the three types of chromatophore, variously expanded, in irregular patches (figure 1). This pattern covers the head and arms as well as the back.

We now come to the white-square and stripe patterns, which can easily be elicited from animals in a small tank. If one blackens the floor and walls of the tank a cuttlefish placed in it receives comparatively little incident light. Its response is to become uniformly very dark in colour, by full expansion of the black chromatophores; it is thus made inconspicuous. If now a white object, such as a porcelain plate, is introduced, clear white areas appear on the body. Three main elements may be distinguished in the black-and-white pattern; a stripe across the head above the eyes; a square in the centre of the back; and symmetrical white bands extending down at either side of the back from the central square (figures 6–9). As can be seen in these figures, the square may appear either with or without the white stripes. As protective devices these patterns are useful both by giving a resemblance to the environment and by disrupting the outlines of the body. They are often accompanied by another kind of white pattern on the black background, brought about by the muscular elevation of papillae containing a concentration of iridocytes; these arise in regular positions along the base of the fin (figure 7). An interesting condition is seen in figure 9. Here the animal is passing directly from the sandy stripe pattern to the white-square pattern, having just been introduced into the dark tank, and the square is appearing first on the half of the body on which is the eye closest to the white plate.

Perhaps the most remarkable of all are the 'terrifying' patterns, which appear and disappear with lightning rapidity. Strong stimulation of the cuttlefish is followed by a series of colour changes of remarkable rapidity, involving the whole body of the animal. A succession of patterns is exhibited, each one enduring for a few seconds only. A strong touch, a violent movement in the visual field, or a disturbance of the posture of the animal, are each sufficient to elicit these changes.

Usually the first result of disturbing the animal is the appearance of two black spots, which arise symmetrically on the back, always in the same position (figure 4). If the animal is fairly gently stimulated, a single spot will appear on the same side of the body as that to which the stimulus was applied. The appearance of the black spots is very soon followed by a total paling of the whole of the rest of the body, so that the spots stand out with startling clarity. This pallor is rarely maintained for more than a second or two, being usually succeeded immediately by a complete change, the total blackening of the body. On further irritation a new pattern may appear: two longitudinal black stripes appear on the back, and the rest of the body turns white again. The lines flicker vividly over the pallid back. The animal's final resource is to eject a cloud of 'ink'; having done this it becomes motionless, and hides inside the black cloud. The cloud remains suspended in the water for a considerable time, and makes further observation of the colour of the animal itself impossible. The sudden display of a conspicuous pattern of colour is known, among other animals, to be a form of warning coloration. The 'terrifying' displays of the cuttlefish may also protect it in another way. The rapid changes from black to white make the animal seem to disappear, even to the acute human eye, and the sudden movement of the conspicuous coloured shapes may startle and divert the predator.

Each particular situation in the cuttlefish's life evokes characteristic colour behaviour; those which accompany mating have been described by R. Bott [1] and L. Tinbergen [8]. No other cephalopod has as extensive a repertoire of patterns. The octopus shows some comparable changes (figures 2 and 3); but the squids, which live in deeper water, though capable of generalized changes, cannot produce conspicuous patterns. These open-ocean creatures often show instead patterns of luminescence in the dark [3], but they are so difficult to keep alive in aquaria that few have studied them.

### THE CENTRAL NERVOUS SYSTEM AND COLOUR CHANGE

The little muscle fibres whose activity controls the colour changes are activated by nerve fibres which arise in the central nervous system of the animal, in lobes of the sub-oesophageal ganglia. It was pointed out some years ago [5] that the colour patterns of cephalopods are thus a visible representation of patterns of nervous activity.

In recent years J. Z. Young and B. B. Boycott



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FIGURE 1 – *Cuttlefish. Side view of the head, with arms to the left. The animal is resting on a shell-gravel bottom, and showing the mottle pattern.* (× $\frac{2}{3}$)

FIGURE 2 – *Octopus. Oblique view from behind. The white patches of iridocytes stand out against a uniform background.* (× $\frac{1}{3}$)

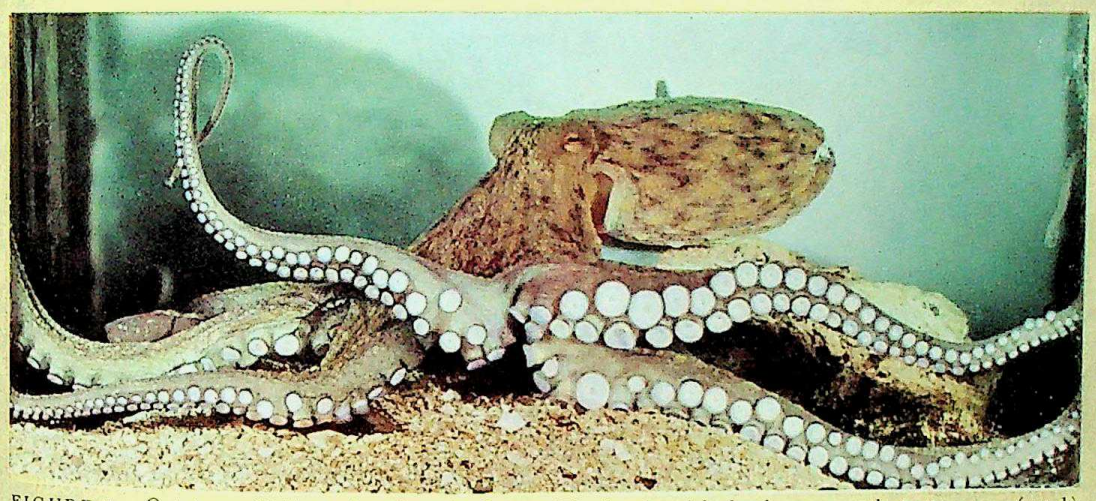

FIGURE 3 – *Octopus. Oblique view from in front. The head and body show a mottle pattern.* (× $\frac{1}{3}$)
*(Photograph by D. Wilson.)*

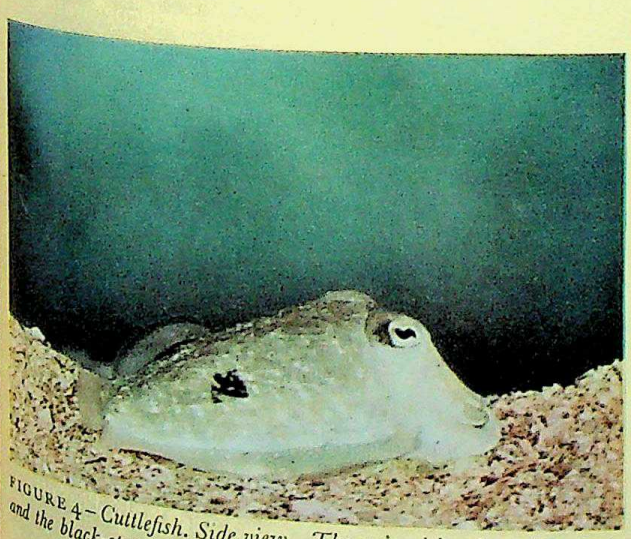

FIGURE 4 – *Cuttlefish. Side view. The animal has been disturbed, and the black-spot pattern is developing.* (× $\frac{1}{4}$)
*(Photograph by D. Wilson.)*

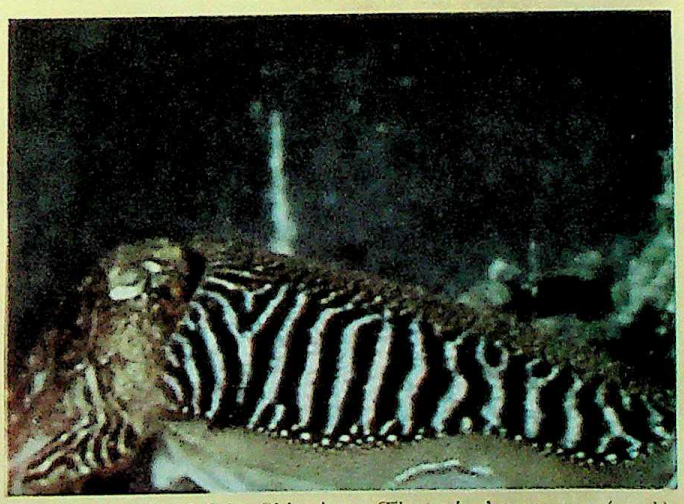

FIGURE 5 – *Cuttlefish. Side view. The 'zebra' pattern.* (× $\frac{1}{3}$)

*(Figures 1, 2, and 5 are from a ciné film on the Naples Zoological Station, made in 1952 by Dr O. Schulz-Kampfhenkel, who reserves all rights.)*



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FIGURE 6 – *Cuttlefish. Dorsal view. White-square and stripe pattern.* ($\times \frac{1}{3}$)

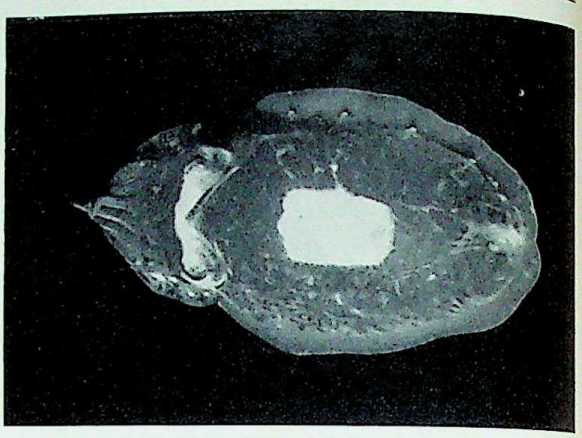

FIGURE 7 – *Cuttlefish. Dorsal view. The white-square pattern, with iridocytes elevated on papillae on the right side of the body at the base of the fin.* ($\times \frac{1}{3}$)

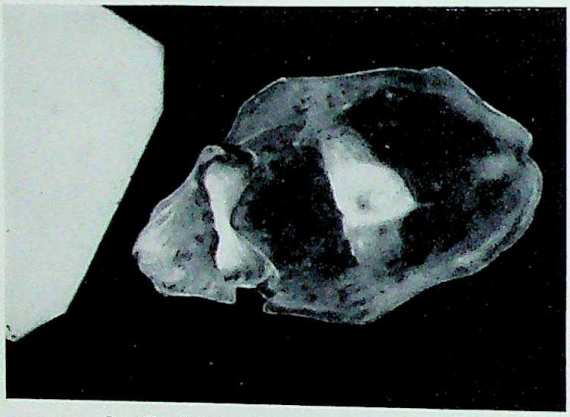

FIGURE 8 – *Cuttlefish. Dorsal view. The animal is lying on a black background with a white plate within sight, and the white-square and stripe pattern is developing.* ($\times \frac{1}{3}$)

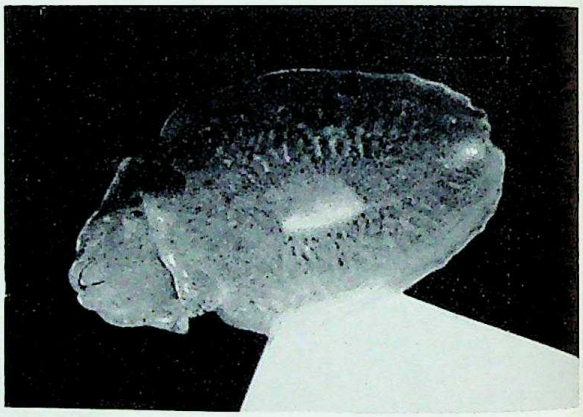

FIGURE 9 – *Cuttlefish. Dorsal view. The zebra pattern is fading and being replaced by the white-square pattern, which is developing first on the side of the body closest to the white plate.* ($\times \frac{1}{3}$)

have been considering this problem as a part of their studies of the behaviour of cephalopods and of the underlying nervous organization. In a preliminary report Boycott [2] gives an introduction to these studies. The chromatophore motor neurons in the sub-oesophageal ganglia are influenced by nerves arising in the supra-oesophageal ganglia, the 'higher centres' of the cephalopod, and these can be excited by fibres from the optic, tactile, and static sense organs. In the chromatophore lobes, the organization of the nervous tissue shows a significant difference between the octopus and cuttlefish and the squid. In the two former animals the mass of nerve fibres characteristic of nerve centres shows a greater regularity of arrangement. There is thus the exciting possibility that the colour changes of these animals may give a key to an extremely difficult general problem: that of correlating different kinds of organization in nervous tissue with differences in behaviour.

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# Chemical aspects of the atomic industry

E. GLUECKAUF

The importance of the roles of the physicist and the engineer in the atomic industry are generally understood, but the extent of the chemical effort involved is still too little appreciated. Nevertheless, it is a fact that plutonium production by means of natural uranium piles requires many more chemists than physicists and engineers together. Atomic power stations must be associated with vast chemical plants for the manufacture and recycling of the fissile materials and for the treatment and disposal of radioactive waste products.

The production of atomic power is based on the ability of certain unstable elements to react with neutrons and, in so doing, to set up a self-supporting chain reaction which can be controlled. The natural uranium pile utilizes this chain reaction, but as natural uranium, mostly uranium 238, contains only 0·7 per cent of uranium 235, the resulting energy is produced in a mass of material so unwieldy that it is difficult to utilize the energy released. To obtain atomic power more economically, we require not only nuclear fuel, but we require it in concentrated form. Such concentrated fuels do not occur naturally and they have to be manufactured by elaborate processes (figure 1). Fuels suitable for combustion with slow neutrons are potentially obtainable in three ways:

1. The isotopes of uranium can be separated and the 0·7 per cent of uranium 235 extracted.
2. Plutonium 239 can be 'bred' by making uranium 238 react with neutrons.
3. Uranium 233 can be 'bred' by making thorium 232 react with neutrons.

The first process seems, at first sight, the simplest, but it requires a high capital investment and consumes vast amounts of electric energy. The second process, which occurs in the natural uranium pile, proves to be the more economical method. The third process, which may well be the process of the future, because of the greater natural availability of thorium than of uranium, is not of interest at present, as it will work economically only with the surplus neutrons from concentrated-fuel reactors.

## PRODUCTION OF PLUTONIUM

The sequence of reactions in the natural uranium reactor is indicated in figure 2. A slow neutron meets a $U^{235}$ nucleus, combines with it to form an excited unstable atom, $U^{236}$, which immediately explodes into two fission fragments and two or three neutrons. On the average, 2·56 neutrons result. The fates of these neutrons are as follows:

1 carries on the chain reaction by combining with another $U^{235}$ atom.
0·9 combine with $U^{238}$ to produce, eventually, plutonium.
0·61 are lost in various ways: in the slowing-down process, as stable $U^{236}$, or by escaping.
0·05 are excess neutrons, which may be utilized either for speeding up the reaction or for making isotopes; if not so utilized they will have to be absorbed in the control rods.

Thus for every kilogram of $U^{235}$ destroyed we obtain 0·9 kg of Pu and 1 kg of fission products. These are contained in quantities of uranium of the order of tons, depending on the burn-up rate of $U^{235}$.

The fission products consist of thirty-five elements, ranging from zinc to gadolinium, i.e. drawn from the middle of the periodic system. Most of them are radioactive, 1 kg representing an original activity of the order of 2 million Curies.[1] This represents 10 kW of radiation power—enough to kill almost instantaneously any living cell exposed to it. It is, of course, this intense radioactivity that so greatly hampers chemical operations.

The chemical problems begin, however, long before a natural uranium pile can even be started. Figure 2 shows that only about 2 per cent of the created neutrons are excess neutrons; absence of these would prevent the pile being started up. If foreign neutron-absorbing materials were present in the pile, even in traces, they would soon raise the proportion of wasted neutrons from 0·61 to 0·66 or above, and so eliminate the excess neutrons required for accelerating the chain reaction. Consequently, all materials going into the making of a slow-neutron pile have to be chemically purified to a degree previously almost unheard of in industrial practice, and analytical methods had to be

[1] One Curie is the decomposition rate of 1 g of radium, or $3·7 \times 10^{10}$ atomic decompositions per second. The unit of energy-release rate is the MeV-Curie, corresponding to $3·7 \times 10^{10}$.MeV/sec, or 0·0054 watt.



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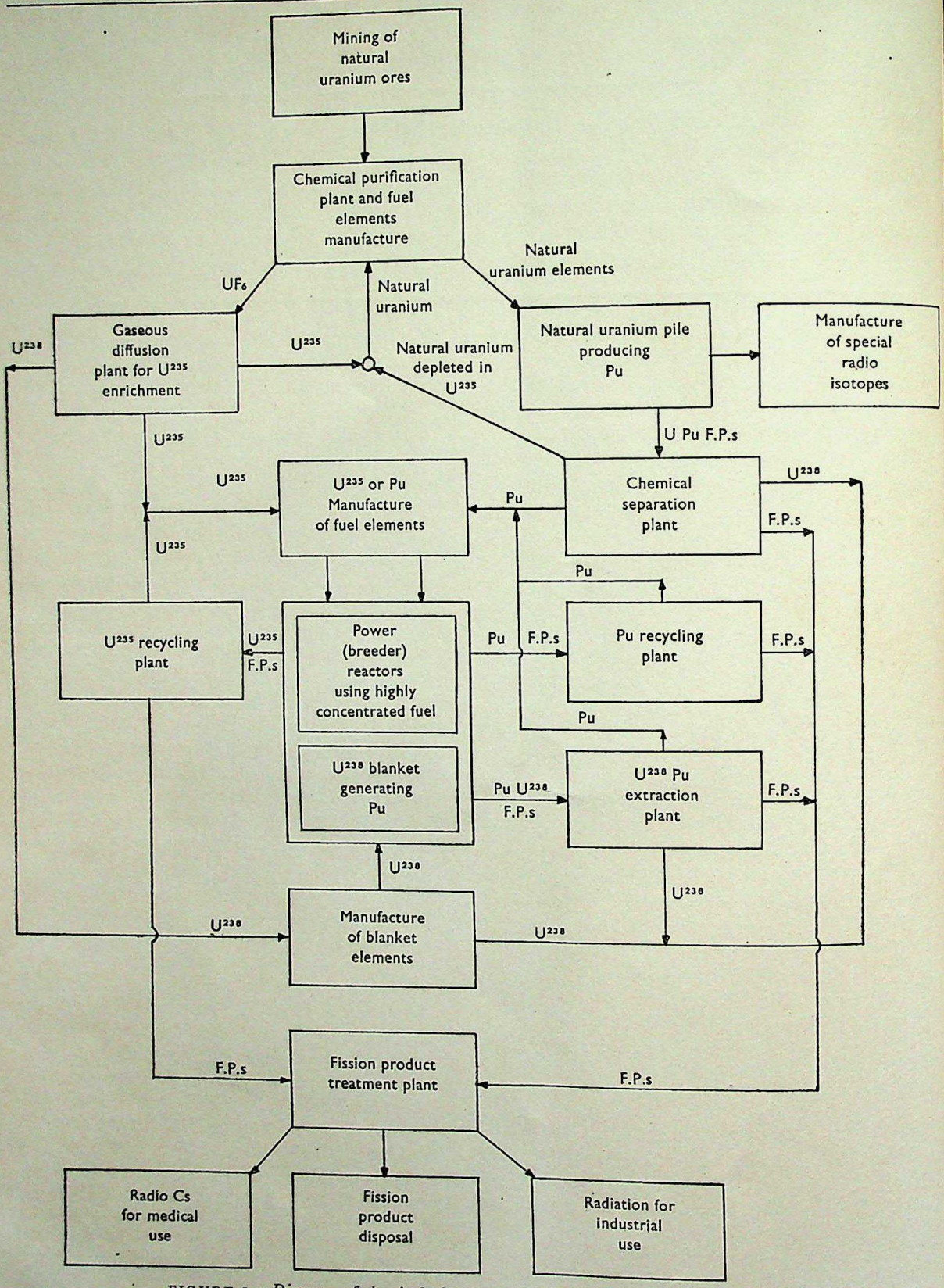


FIGURE 1 – *Diagram of chemical plants associated with an economic power reactor.*



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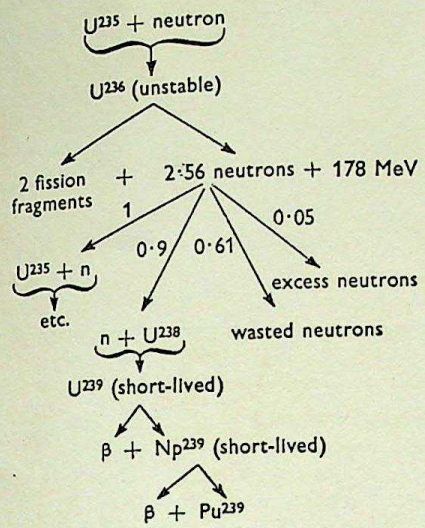


FIGURE 2 – *Fission scheme.*

developed for the determination of many impurities present to the extent of only a few parts per million. The small proportion of excess neutrons available in a natural uranium pile causes still further complications. Once the pile is running it produces its own poisons in the form of the fission products, some of which consume slow neutrons. Long before an appreciable fraction of the $U^{235}$ has been used up, these impurities begin to consume neutrons at such a rate that the reaction in the pile is no longer self-sustaining. It is, therefore, a feature of natural uranium piles, and of all slow-neutron reactors, that the fissile materials have to be regularly purified of their fission products.

### CHEMICAL SEPARATION DURING RECYCLING

The composition of the material that has to be dealt with is shown in Table I, which tabulates the quantities and the radiative intensities of the fission products several months after their removal from a pile. After this interval the more short-lived radioactive materials have already decayed, thus greatly simplifying the handling problem.

As there are present also iron, nickel, cobalt, and silicon as impurities, some 900 g of plutonium, about 1000 kg of uranium, and 1 or 2 g of americium, it will be seen that the mixture is quite a comprehensive one, deriving from all groups of the periodic table. Fortunately, the problem for the plant designer is not to separate the mixture into all its constituents, but to divide it, as sharply as possible, into three parts:

1. Plutonium for use as concentrated fissile material.

TABLE I

*Main fission products from 1000 g of $U^{235}$*
(*150 days irradiation, 30 days cooling*)

| *Group* | *Element* | *g.* | *Curies* |
|---|---|---|---|
| 1 | Rb | 14 | — |
| | Cs | 108 | 2 900 |
| 2 | Sr | 39 | 110 000 |
| | Ba | 39 | 66 000 |
| 3 | Y + rare earths | 308 | 675 000 |
| 4 | Zr | 114 | 119 000 |
| 5 | Nb | 5 | 200 000 |
| 6 | Mo | 84 | 190 |
| | Te | 14 | 1 200 |
| 7 | Tc | 26 | 170 |
| | I | 6 | 11 000 |
| 8 | Ru, Rh, Pd | 74 | 235 000 |
| | Kr + Xe | 128 | 6 300 |
| | | Total activity: | 1 426 760 |

2. Uranium for recovery and recycling.
3. The remainder, including all the active fission products.

Four principal methods of effecting this division immediately suggest themselves:

1. Solvent extraction.
2. The classical method of separation by precipitation from solutions.
3. Separation by high-temperature distillation of halides.
4. Separations using ion-exchange columns.

All these methods have their advantages and their disadvantages, but none of them can be as easily and as safely applied to continuous operation as solvent extraction, which lends itself readily to remote control. Since both uranium and plutonium nitrates are much more soluble than the nitrates of any other cations in water-insoluble organic solvents containing oxygen (such as ethers and esters), their separation from the bulk of the fission products by solvent extraction is practicable.

The chemistry of uranium and plutonium in these solvents is itself most interesting [1]. The nitrates are almost completely unionized. They are hydrated, on the average, with four water



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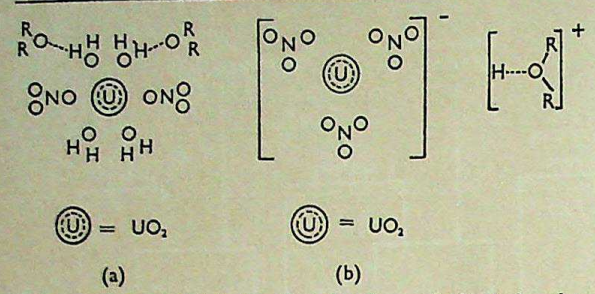


FIGURE 3*a* – *Model of undissociated uranyl nitrate in ether solution.* 3*b* – *Model of tri-nitrato-uranyl ion.*

molecules, which are carried into the organic solution, where further solvation with the organic solvent occurs. Thus uranyl nitrate, in a neutral ether solution, is roughly as shown in figure 3(*a*), where eight oxygen atoms surround each uranium atom. In the presence of strong nitric acid, however, the uranyl nitrate in the solution becomes partly ionized, forming an unhydrated trinitrato anion, $[UO_2(NO_3)_3]^-$, again with eight oxygen atoms around the uranium (figure 3(*b*)). Research has shown that the ability of solvents to extract uranium—or, more precisely, the free energy of the extraction equilibrium—is, for a given type of solvent, a simple function of the oxygen : carbon ratio of the solvent; it is almost independent of the molecular size or arrangement of the solvent molecules (figure 4).

As mentioned, the solvent extraction process depends upon the difference in the extractability of uranium and plutonium nitrates from that of all other nitrates. At the same time, uranium and plutonium differ greatly between themselves in the stability of their various valencies. Both can exist in the valencies 3, 4, 5, and 6, but the most stable valency of uranium is 6 (nitrate solvent-extractable), while the most stable valencies of plutonium are 4 (nitrate solvent-extractable) and 3 (nitrate not solvent-extractable). It is therefore possible, by the use of a reducing agent, to separate uranium and plutonium from each other by further solvent extraction.

Figure 5 shows a possible process of dissolving, extraction of uranium and plutonium in the oxidized state from fission products, separation of plutonium by aqueous extraction of the resulting organic solution under reducing conditions, and finally the extraction of the uranium back into water; at the same time the solvent is regenerated and goes back into the first column.

Chemical works in which such operations with radioactive materials are carried out are examples of extreme cleanliness. A working deck in the

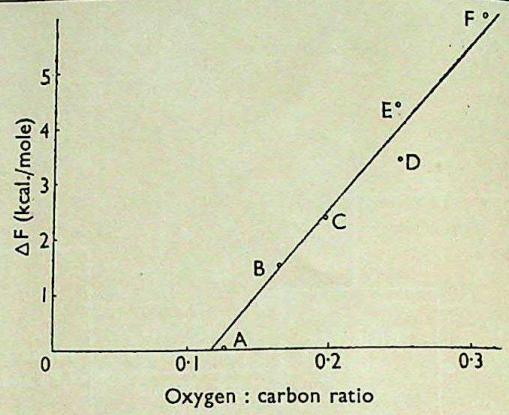


FIGURE 4 – *Free energy of solvent extraction of uranyl nitrate expressed as a function of the oxygen : carbon ratio of the ether.* $A$ = *n-dibutyl ether,* $B$ = *di-isopropyl ether,* $C$ = *di-butyl cellusolve* $[C_4H_9—O—C_2H_4—O—C_4H_9]$, $D$ = *di-ethyl ether,* $E$ = *di-butyl carbitol* $[C_4H_9—O—C_2H_4—O—C_2H_4—O—C_4H_9]$, $F$ = *penta-ether* $[C_4H_9—O—(C_2H_4—O—)_4C_4H_9]$.

tower of the primary separation plant at Windscale is remarkable for the absence of any spectacular apparatus. Only a few valves, flow indicators, and pressure gauges are seen outside the thick concrete wall. Inside this cell, which has not been entered since the factory began operating several years ago, there are no pumps, no valves, no movable parts; only extraction columns, tanks, and miles of stainless steel piping, in which the flow of the liquids is controlled by air-pressure and gravity, using the simplest possible devices. Figure 6 shows the separation plant with its 65-metre extraction tower. Its massiveness can be judged by the fact that it took 30 000 tons of concrete to build it. Chemical processing does not, of course, stop with the primary separation. Both the uranium and the plutonium have to be further purified; after removal of the radioactive fission products, however, this can be done by essentially conventional processes.

Extensive ancillary laboratories are, of course, necessary for the strict control of these processes. A principal difference between these and the research laboratories of other chemical industries is the predominance of ventilation equipment. Radioactive dust is an even greater health hazard than radiation is, and as many as sixty air-changes per hour may be required in laboratories handling plutonium; both radiation monitors and dust-activity monitors are a prominent feature of these laboratories. Under the prescribed conditions work is absolutely safe, and the permitted tolerance of radiation is in fact less than that produced by wrist watches having luminous dials containing small amounts of radioactive material.



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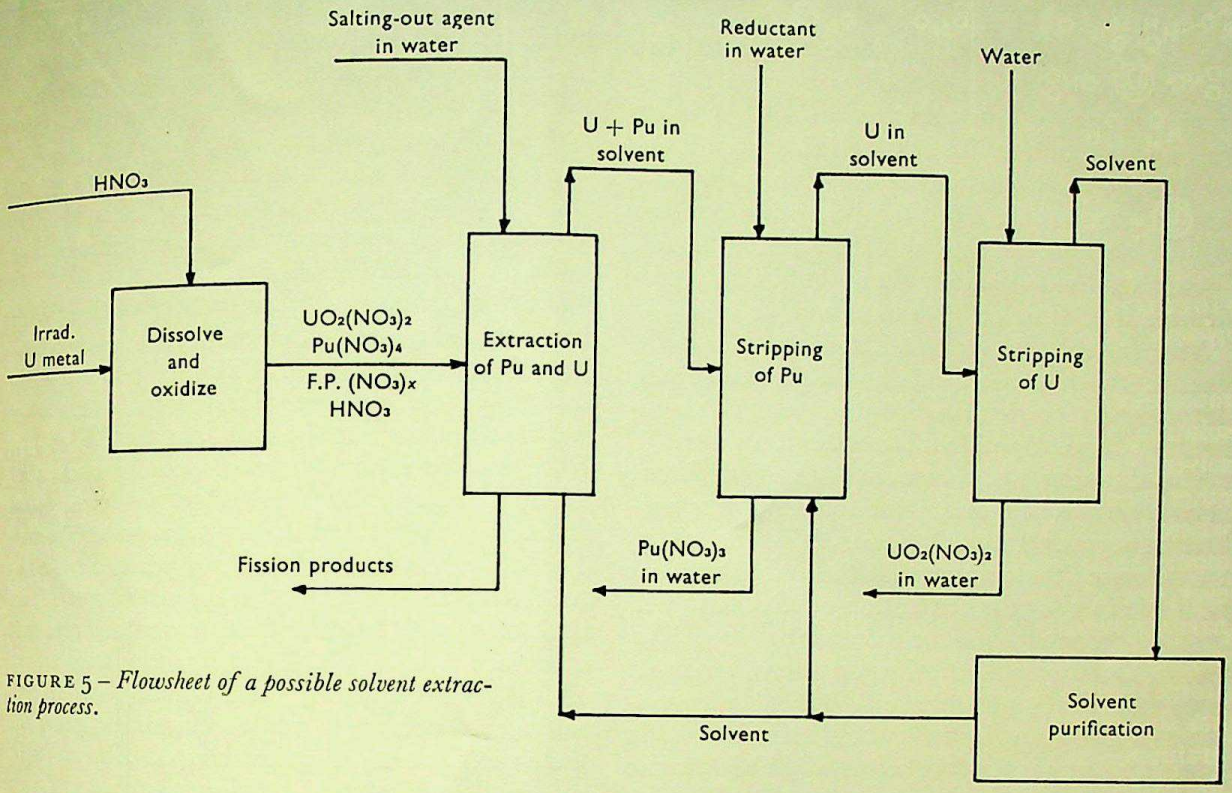
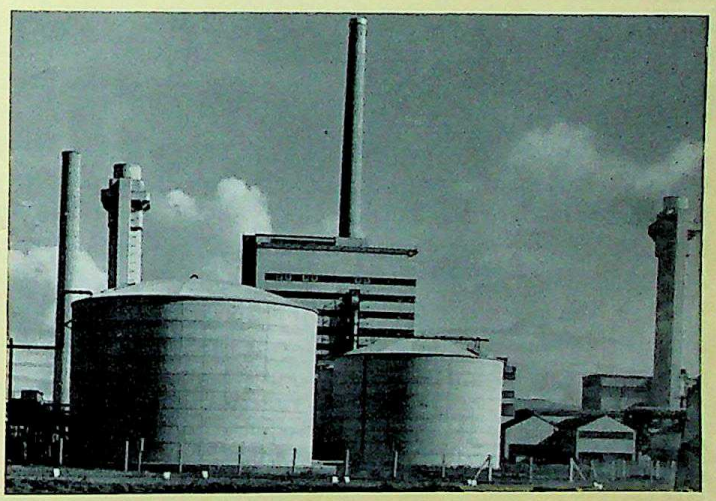



FIGURE 5 – *Flowsheet of a possible solvent extraction process.*

FIGURE 6 (*right*) – *External view of Windscale separation plant. In the background can be seen the stacks of the production piles, with their filters at the top.*



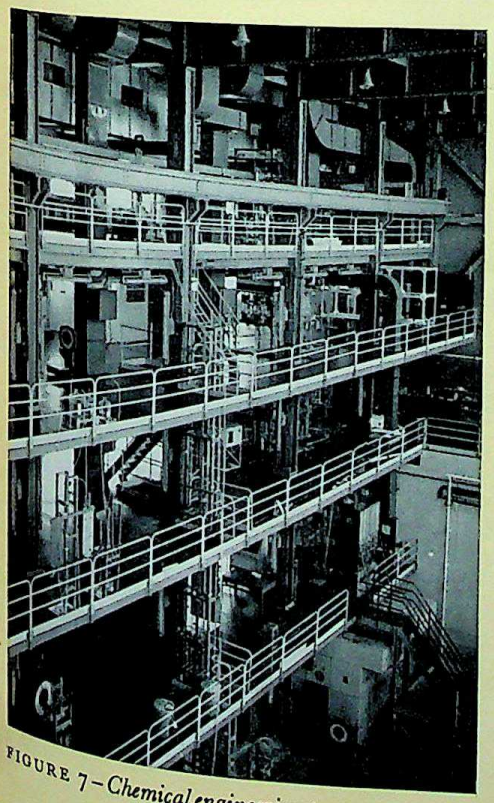


FIGURE 7 – *Chemical engineering tower at Harwell.*

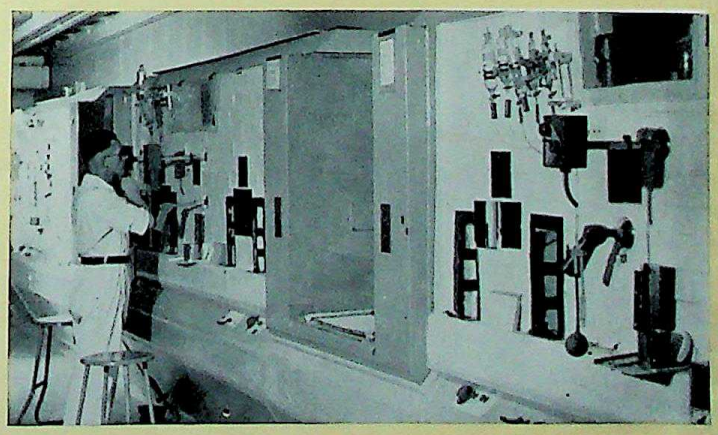


FIGURE 8 – *Handling of radioactive chemicals behind a lead wall.*



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DISPOSAL OF FISSION PRODUCTS

Like other industries, the atomic industry has the problem of disposing of its waste products, but in this case they are more toxic and dangerous than in most others. The activities are too long-lived, and too intense, for the waste involved to be thrown into the sea. Even if mixed with concrete and sunk off the Atlantic shelf, the danger to fish —and so to human health—is not sufficiently predictable to permit such an irretrievable step. At present, however, the quantities are not so large as to prevent permanent storage in stainless steel tanks, although this is expensive. For the moment, therefore, the disposal problem is not a serious one.

The situation will, however, be very different when a serious programme of atomic power production begins.[1] Britain's National Coal Board [2] has expressed the opinion that the amount of coal available in 1965 for generation of electricity will be of the order of 50 million tons (see figure 9). The British Electricity Authority, on the other hand [3], expects to need to increase its coal consumption at a rate which by 1965 would bring it up to 65 million tons annually. It seems that only atomic energy can bridge this anticipated gap. To produce energy from atomic sources at the necessary rate would require the building of about fifty reactors by 1970, consuming altogether about eight tons of nuclear fuel annually, and producing an equal amount of fission products. In terms of activity this means production of about 1000 million MeV-Curies, even allowing for one year's decay. This is equivalent to the radiation from 200 tons of radium.

When working on this scale disposal of fission products is bound to become a serious problem. A high degree of chemical concentration would obviously be necessary before the fission products could be stored economically. In order to do this, the hundreds of times larger quantity of chemicals which have been added during the primary separation process would have to be separated. These problems are now being actively investigated at Harwell by both physical chemists and chemical engineers; parallel investigations are proceeding in the United States [4].

Many suggestions for methods of dealing with the waste have been made, and two general tendencies can be discerned. The first is to bury the fission products, or their solutions, on land, under conditions such that they could not possibly return to the surface until their radioactivity had completely decayed. The second is to reduce the products to minimal bulk, in a form not easily dissipated, and to keep them under permanent control. Whatever method is accepted, the cost of the disposal process must not, for economic reasons, affect the cost of the electricity by more than a very small fraction of a penny per kW-hour of electricity produced. This might represent about 5 per cent of the cost of production, ignoring distribution and overhead expenses, which amount to several times the cost of fuel. Such considerations considerably restrict the methods which might be employed, and virtually eliminate any involving transport of the fission products over long distances. In the choice of sites for atomic factories waste disposal has always been important, and it is likely to become still more so as the quantities of the waste increase.

At the moment it appears that, whatever the method of final disposal, three chemical processes are likely to have to be undertaken:

1. Concentration of the waste solutions, presumably by removal of the bulk of volatile inactive constituents by evaporation.
2. De-acidification of the greatly reduced solution volumes, by acid extraction, electrolysis utilizing anion-exchange membranes, or neutralization.
3. Separation of fission products into long-lived products of more than five years half-life, and shorter-lived elements.

The first two processes offer obvious advantages for storage of any type. The third would permit us to accept for the shorter-lived materials the slight, but finite, risk connected with direct disposal in the ground; within twenty years their activity would have become insignificant. As this method is, on suitable sites, very inexpensive, it

[1] See 'A Programme of Nuclear Power' (Her Majesty's Stationery Office, 1955), published as we go to press.

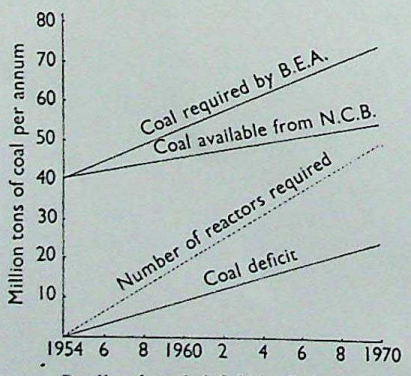


FIGURE 9 – *Predicted coal deficit in Britain and number of reactors required to cover it.*



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would permit greater expenditure on the disposal of the smaller bulk of really dangerous, long-lived materials, such as $Cs^{137}$ and $Sr^{90}$; these would most probably have to be permanently controlled.

### UTILIZATION OF FISSION PRODUCTS IN THE FUTURE

At the moment it is the nuisance value of the fission products which demands detailed consideration, but there is no reason why this should always be so. $10^9$ MeV-Curies of fission products represent a unique radiation source of great potential chemical activity, with an uninterrupted supply of 5400 kW. Today we know little about how such intense radiation sources could be economically used in chemical reactions, but even as a source of heat—reckoned at 1d. per kW-hour—the annual value is about £200,000. As a radiation source the potential value must be many millions of pounds annually. It is obvious that such a source of energy cannot be disposed of as mere waste, and investigations are proceeding to develop methods of utilizing these radiations [5] in large-scale industrial processes. Among suggested uses are those of initiating and speeding up chain reactions, like the polymerization of ethylene and the cross-linking of long-chain polymers. Other fields where the use of radiation on a large scale is contemplated are the preservation of certain foods and the sterilization of pharmaceutical products. Other profitable industrial uses may well be discovered by the time really large quantities of fission products become available.

Most of the radiant energy of the processed fission products is contained in four elements, which have greatly differing properties. There are the long-lived isotopes of caesium (half-life 32 years, emitting valuable $\gamma$-radiation), and of strontium (half-life 20 years, emitting pure $\beta$-radiation). The former is bound to contribute greatly towards the expansion of radiotherapy in cancer treatment, though this field alone will require only a minute fraction of the caesium produced. Then there are the shorter-lived isotopes, $Zr^{95}$ (with its daughter Nb), and $Ce^{144}$ (with its daughter Pr). The former emits an intense $\gamma$-radiation which, for a given weight, is about 100 times more intense than that of caesium, and it may find useful applications when small $\gamma$-sources of an intensity of about one million Curies are required. $Ce^{144}$ emits a not quite pure $\beta$-radiation, and on account of its shorter half-life has a much higher specific $\beta$-intensity than has $Sr^{90}$.

It is not generally realized that the fission products contain also a number of inactive chemical species which are of considerable value, even though this value is dwarfed by that of the reactor energy and even by that of the radiant energy of the fission products. Among these inactive products the most valuable is xenon, which, on the basis of eight tons of fissile material, would be produced at the rate of 100 $m^3$ per year. The present price of this gas is £12 10s. per litre. It is, of course, difficult to predict the future price of chemicals which at the moment are very rare and for which there is little or no demand. Other valuable inactive products, calculated on the same basis, will be:

| | *kg/year* | *Present price of commercial products* |
|---|---|---|
| Ru .. | 350 | £300/kg |
| Rh .. | 130 | £600/kg |
| Pd .. | 60 | £300/kg |

An interesting product, which does not exist at all in nature, is element 43, technetium. This would be produced at the rate of 200 kg/year. Its radioactivity, it has a half-life of $2 \times 10^5$ years, is virtually negligible, and useful applications for this element may be discovered. It is, of course, too early to say whether the cost of processing will permit an economic recovery of these materials from highly active mixtures, but it may well be that the possibility of recovery at a later date will be taken into account when selecting methods of disposal.

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# Some early English instrument makers

DEREK J. PRICE

In the early days of science the instrument makers, generally as a group but sometimes individually, played an important role, and nowhere more so than in Britain, where their craft flourished exceedingly. Informal meetings in and near the shops of instrument makers provided an opportunity for the exchange of ideas before the organization of some of the early scientific societies. Their instruments advanced science, especially astronomy and navigation, and many are exceptionally fine examples of the craftsmanship of their day.

The earliest years of the Scientific Renaissance, in the sixteenth and seventeenth centuries, were marked by an enormous increase in the number of 'little men of science.' Great men there certainly were too; but in 1500 they were isolated scholars, whereas by 1700 they were at the centre of a considerable group of people who made and sold scientific devices or who bought and used such devices in the course of their daily work.

The instrument makers and engravers, the teachers of navigation, the surveyors and other mathematical practitioners, were for the most part obscure people. Many of their instruments survive, however, some having been preserved as examples of the finest craft of the metalworker. A few of their manuscripts and books survive too, but in general we know little of the lives and the everyday work of these men. Yet their workshops, their trade guilds, and the places in which they met, were the first instances of organized activity in science outside the universities. At first they were artisans employed by the mathematicians and astronomers to make instruments more complicated, more accurate, or more lavish than they themselves could make unaided. Later, however, the instrument makers themselves acted as a centre, and attracted a clientele of scholars and professional practitioners as well as amateurs of science who were excited by 'the new philosophy.' Still later, groups of these scholars, practitioners, and amateurs formed the basis of the *Accademia del Cimento* at Florence, the *Académie des Sciences* at Paris, the Royal Society of London, and the other national academies which are customarily regarded as the concomitant of modern organized scientific inquiry.

Nowhere was the role of the instrument maker more important than in England. The craft had started in Nuremberg late in the fifteenth century, probably under the inspiration of Regiomontanus, the 'father of modern astronomy.' By the middle of the sixteenth century it had spread to Augsburg and other towns in Germany. Thence it came to Louvain and, with a quickening of the pace, instrument makers began to flourish all over Europe. England made a comparatively late entry into this field, but when it came the craft took root firmly in the metropolitan and maritime centre of London, and it increased prodigiously. Elsewhere in Europe the situation was not so favourable. In Italy and in France there were a number of fine craftsmen, but no active school of instrument-making developed; in Louvain the workshops were overrun and dispersed during the invasion by Alexander Farnese in 1578; in Germany the craft became moribund soon after 1600 and declined until it was almost extinguished by the Thirty Years War. By 1650 London had become the greatest European centre for the manufacture of scientific instruments, and other countries were beginning to be concerned about their lack of comparable craftsmen and facilities. London, however, had established such a lead that it was able to maintain its position until the dying out of the old school of instrument craftsmen as a consequence of the new era of factories and mass-production.

The question of who was the first English instrument maker is largely one of definition and in consequence is very difficult to answer. In the widest sense, the first tools used by primitive man were scientific instruments and the earliest shadow-measurement involved the making of a sundial. Again, up to the end of the Middle Ages scientists designed and made their own instruments; the remarkable work of the astronomers at Merton College, Oxford, in the thirteenth and fourteenth centuries led to the making of many new and complicated devices.

Probably the first important contact between England and the new but flourishing German schools of instrument-making came through the



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Bavarian, Nicolas Kratzer (1486–1550), who was appointed a tutor in the household of Sir Thomas More, and later as astronomer- and horologer-royal to Henry VIII and as a lecturer at Oxford. He is well known through a portrait of him, now in the Louvre, by his friend Holbein (see figure 3). Some of Kratzer's instruments shown in this portrait are also to be seen in the painting by the same artist of 'The Ambassadors,' now in the National Gallery, London (figure 5). While at Oxford he taught the 'Doctrine of the Sphere' and constructed elaborate sundials; one of his dials, made for Cardinal Wolsey, is preserved in the Museum for the History of Science, Oxford.

Kratzer may be regarded as an astronomer rather than as an artisan. If he awakened interest in instruments, he seems to have done little or nothing to train others to make them; perhaps this arose in part from the fact that he never mastered the English language.

The second contact with the European schools was more productive. This time it was made by a Protestant refugee from Flanders, who came to London from a village near Liège and changed his name from Thomas Lambrit to Thomas Gemini (fl. 1524–62). He was a skilled engraver by trade, and seems to have established a reputation by engraving the plates for the English edition (1545) of the 'Anatomy' of Vesalius. Gemini seems to have had some contact with the Arsenius family, instrument makers in Louvain, who ran a workshop which had been started by their relative, the astronomer Gemma Frisius, and his collaborator, Gerard Mercator. Three fine astrolabes by Gemini that have been preserved are executed in a style very similar to that of Arsenius; one of them was made for Sir John Cheke, and is now at the Royal Observatory of Belgium, and the two others for Queen Elizabeth; one of the latter is at Oxford and the other at the National Maritime Museum, Greenwich. Besides making instruments, Gemini engraved maps and published books, among them Leonard Digges's 'Prognostication' and 'Tectonicon,' which describe many new types of instruments.

The first native Englishman to make fine instruments was undoubtedly Humphrey Cole (1530?–91), a north-countryman whose chief employment was as an engraver and die-sinker, assisting William Humfrey at the Royal Mint. He also worked as an engraver for the printer William Jugge and as a technician for the Mineral and Battery Works, which established brass-founding in England on a firm footing. Cole's work is in some respects very similar to that of Gemini; this supports the suggestion that as a young man he might have learned his art as apprentice to Gemini, then the only instrument maker resident in London. He may also have been related to Jacob Cole, who lived in London and was a brother-in-law of Abraham Ortelius, the famous Antwerp geographer. If this were so it would establish yet another link with the Low Countries.

As regards quality of workmanship and engraving Cole is second to none, and the range of instruments which survive shows that he was able to turn his hand to everything. There are astrolabes and all sorts of sundials, theodolites and gunners' compasses, a mariners' astrolabe, a nocturnal, an armillary sphere, compendiums which contain almost a miniature observatory (including one made for Sir Francis Drake and another for his printer friend, Jugge), and the complete instrumental equipment for Martin Frobisher's first voyage in search of the North-west Passage. He was certainly a great master of his craft; nevertheless we know from petitions and the few contemporary references that he was destitute in his old age and died a poor man.

Even within Cole's lifetime the number of instrument makers in London had begun to multiply. A contemporary advertisement[1] reminds the reader that 'Scales, compasses, and sundry sorts of Geometricall instruments on metall, are to be had in the house of Humfrey Cole, neere unto the Northe dore of Paules, and at the house of John Bull at the Exchange Gate: in wood, at John Reades in Hosier Lane, at James Lockersons dwelling neere the Conduite at Dowe gate, and at John Reynolds at Tower Hill. . . . I have thought good to give advertisement hereof, because many that would provide such things, knowe not where to have them.'

In addition to these men there are two whose names are sometimes mentioned with Cole's, and whose style of work and design of instruments indicate that they were probably apprenticed to Cole, or at least trained by him. Both men, James Kynfin (fl. 1569–1610) and Charles Whitwell (fl. 1591–1606), made many instruments for Sir Robert Dudley (figure 2). A number of signed instruments are still preserved in Florence, where Dudley lived in exile. Kynfin made also a fine pocket dial for Robert Devereux, Earl of Essex, and in a letter dated 1609 he describes himself as

[1] Edward Worsop, *A Discoverie of sundrie errours and faults daily committed by Lande-meaters ignorant of Arithmetike and Geometrie.* London, 1582.



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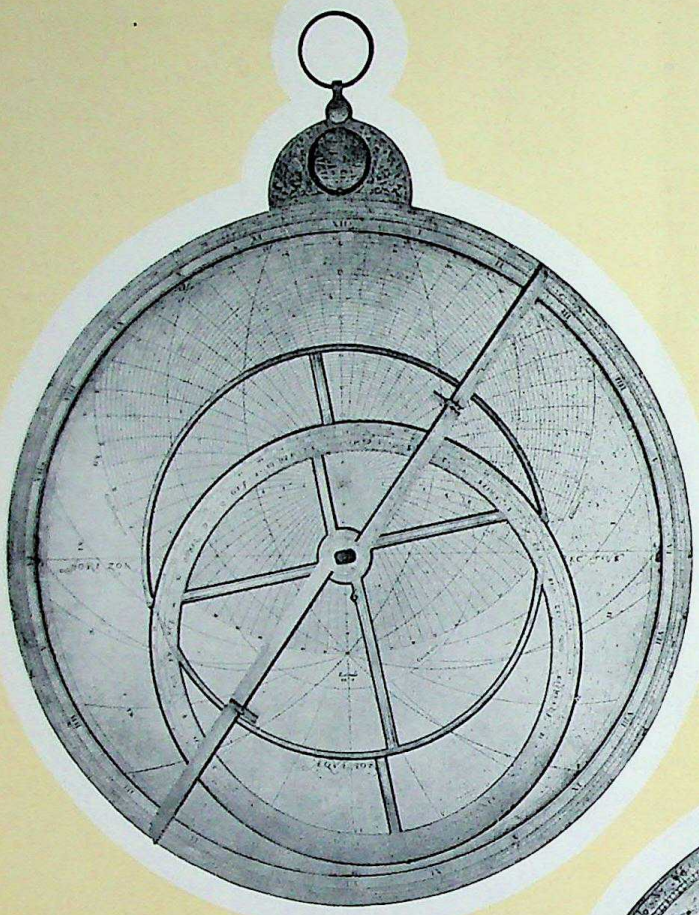

FIGURE 1 – *The two-foot astrolabe of Humphrey Cole.* (Reproduced by courtesy of the Society of Antiquaries of London.)

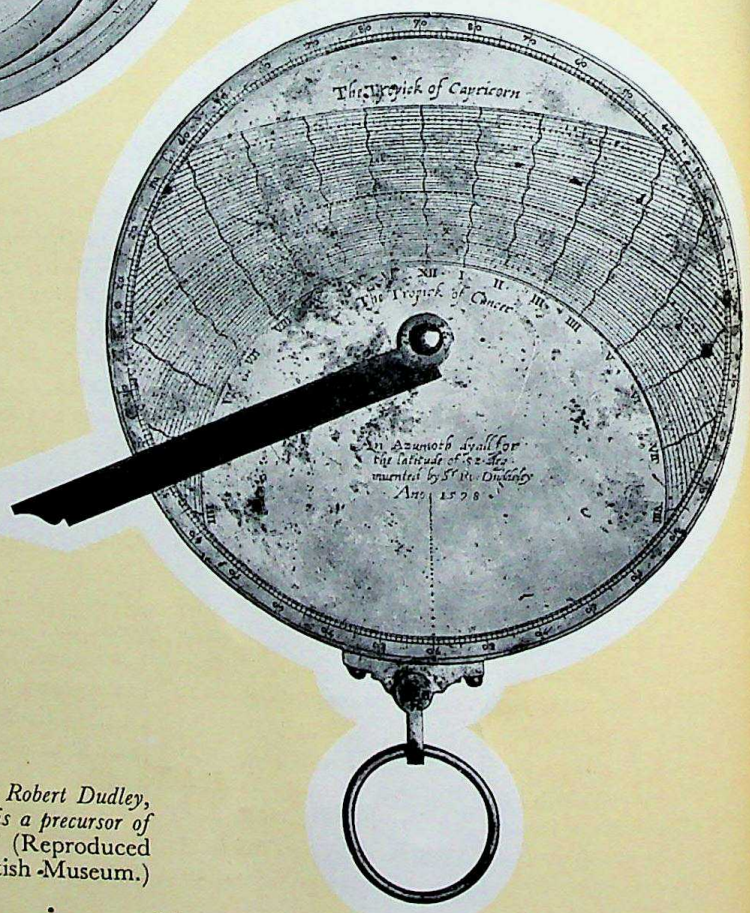


FIGURE 2 – *Azimuth dial invented by Sir Robert Dudley, probably made by Whitwell or Kynsin. It is a precursor of William Oughtred's 'double horizontal dial.'* (Reproduced by courtesy of the Trustees of the British Museum.)



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FIGURE 3 – *Holbein's portrait of Nicolas Kratzer.* (By courtesy of the Louvre, Paris.)

FIGURE 4 – *Elias Allen, with a variety of instruments. Engraved by Hollar from a painting (now lost) by H. Van der Borcht.* (Reproduced by courtesy of the Director of the Science Museum, South Kensington.)

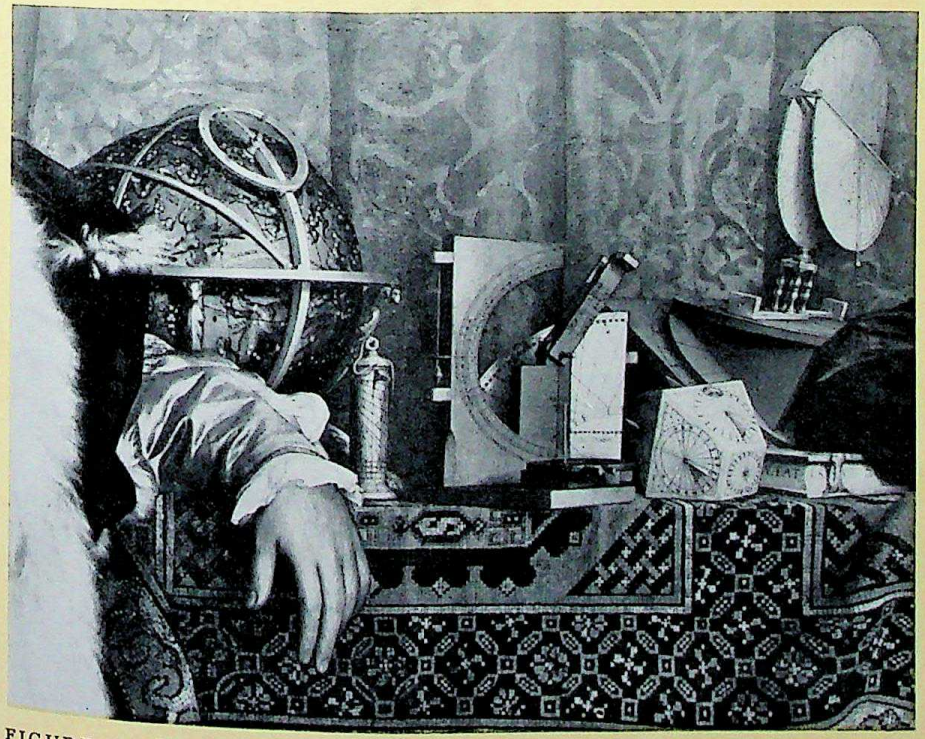

FIGURE 5 – *Detail of 'The Ambassadors' by Holbein, showing globe and a variety of measuring instruments.* (Reproduced by courtesy of the Trustees of the National Gallery, London.)

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a servant to Prince Henry and says he has worked for forty years on certain 'engines of war.' About Whitwell we know almost nothing apart from his signed instruments and the fact that his address was later used by the doyen of English instrument makers, Elias Allen (fl. 1606–54), who may therefore have been his successor and perhaps his apprentice.

Almost uniquely among such artisans, Allen attained sufficient importance for his portrait, a very fine one, to have been preserved. It is reproduced here as figure 4. It was painted by H. Van der Borcht and engraved by Wenceslaus Hollar in 1660, six years after Allen's death. It shows him as a stocky man with beard, moustache, and straggly hair, with a bench full of unfinished instruments before him and others hanging on the wall. He was born near Tonbridge, Kent, probably in the village of Ashurst, where he lies buried; a dial presented by him is still preserved in the churchyard there. As a young man he undertook estate surveys (e.g. in Oxfordshire in 1609), but he was well established in London by 1611. From about 1630 onward, mentions of him and signed and dated examples of his work become very frequent, and in 1636 he was elected Master of the Clockmakers' Company, being the first instrument maker to hold that office. His shop, at the sign of the Horse Shoe, 'near Essex Gate, over against St Clement's Church, Strand, outside Temple Bar,' was known and commended by practitioners, writers, and amateurs of science.

Allen occupied some sort of official position in the rapidly increasing community of instrument makers. It was he who made the facsimile of the brass standard yard at the Guildhall, and it is he who is named by Robert Hooke as the chief of 'the club of instrument makers,' an organization about which, unfortunately, nothing else seems to be known. One supposes that the mathematicians, surveyors, navigators, and amateurs of the day would have found the instrument makers' shops—where they commissioned work for themselves and their patrons—and the neighbouring taverns (and later coffee houses) useful places for the exchange of ideas and for informal discussion of new discoveries. It was clearly to the instrument makers' advantage to foster the experimental interests of their customers. By 1650 there must have been at least thirty instrument makers working in London; after the turn of the century there was a sudden increase in interest which made their numbers grow faster than ever before. The average rate of publication of books on 'practical mathematics' jumped from about two a year before 1650 to nearly seven a year after. This was the same ferment of activity which, a decade later, led to the formal foundation of the Royal Society.

With such a large population of instrument makers it is almost impossible to trace all the successions of masters and apprentices. In the case of Elias Allen we know that his son or nephew John Allen (fl. 1632–7), was taken into the business. In addition he had an apprentice, Ralph Greatorex (1625–1712)—John Aubrey gives him the title Captain—who, like his master, was the personal friend and correspondent of William Oughtred, the mathematician, who designed many instruments. Greatorex worked for many of the early members of the Royal Society, including the diarist Samuel Pepys, who often mentions him.

From Greatorex the line extends to his apprentice, Henry Wynne (fl. 1654–1709), and in turn to Wynne's apprentice, Thomas Tuttell (fl. 1695–1702), both of them well known from fine examples of their work. There, after six generations, one loses trace of that particular branch, but by that time there are many others, and it seems pointless to attempt to trace them all back to Gemini or Cole. Throughout this period it is no dead tradition that is being handed down from master to apprentice. All the time there were new types of instrument being designed and new techniques and materials being used in their construction. Some of the instrument makers started to construct optical devices such as microscopes and telescopes, though this work was later claimed as the prerogative of members of the Spectaclemakers Company—more general craftsmen had followed the lead of Elias Allen by joining the Clockmakers Company *en bloc* in 1667.

Gradually, towards the end of the seventeenth century, a slow change becomes apparent in the style and execution of the instruments. Ornamentation and beautiful engraving tend to disappear on all but 'presentation models' and it is replaced by the more impersonal and functional utilitarianism of modern instruments. The art of the instrument maker was being superseded by a large-scale industry, and meetings of the Royal Society and other organizations had taken over the functions of the informal discussions.

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# Crustacean colour change and neurosecretion

SIR FRANCIS KNOWLES

Some of the colour changes which crustaceans make in response to stimuli, such as illumination and shade of background, have long been known, but it is only comparatively recently that the underlying mechanisms have begun to be understood. Research has shown that crustaceans have a complex neurosecretory system, and it seems that part of this has evolved in response to a need for fast, yet maintained, control of the colour changes.

Each day and night all living things make many delicate and precise adjustments to their changing environments, and nowhere is this more evident than in the elaborate colour-changes of crustaceans. Some of these, slow, regular and predictable, are synchronized with the movements of the Sun, the Moon, and the Earth, with dawn and nightfall, the tides and the seasons; others are adaptive responses to illumination and background.

During the past few years Brown and his collaborators have carried out detailed investigations on the fiddler crab (Uca) which show that the overall colour of this animal alters rhythmically. The interval between lightening and darkening is regulated by the interaction of two rhythms—a diurnal one and a tidal one. The crabs darken during the day and become pale at night, but the moment of maximum darkening in any individual is synchronized with the time of low tide on the beach where the animals live; consequently it moves forward each day as the time of low tide advances. Both these rhythms are persistent and will continue even if the animals are brought into the laboratory and kept in permanent darkness. Even if the environment is kept constant the crabs continue, in darkness, to change colour in harmony with their late companions on the beach. When those on the beach are taking on their darkest hue as a protection against sunlight and predators as the sun rises and the tide recedes, their captured comrades, who may have been kept in darkness for as long as a month, are also becoming their darkest. The crabs seem to have within them a biological clock which shows a most remarkable resistance to temperature change. Altering the temperature between 6° and 26° C did not alter the diurnal or tidal rhythms, though these could be changed by exposing the animals to unusual periods of illumination. These experiments and their implications have recently been summarized by Brown [1].

It is possible that these rhythms of Uca are characteristic of crustaceans as a whole, but the more dramatic and complex colour changes of crustaceans are those which are associated with sudden and irregular changes of background and illumination as the animal moves among sand, rocks, and weeds. Study of the adaptive colour changes that cause the shade and the pattern of the animal to match the background has revealed a remarkable neurosecretory system of control having many features of general biological interest.

## CRUSTACEAN COLOUR

It is little more than a hundred years since colour change in crustaceans was first recorded, though colour changes in the lower vertebrates have attracted the attention of naturalists since the earliest times. The colours of crabs, shrimps, or prawns at first sight seem to be dull when compared with the brilliant colours of some fishes and reptiles, but under the microscope the dull overall colour can be seen to be the result of an interplay of brilliant pigments of many colours, contained in delicately branched chromatophores (plate I). Independent movements of these pigments result in a very close matching of the body colour of the animal with the background on which it rests.

Although the different states of a chromatophore are described as 'expansion' or 'contraction', it is generally accepted that the fine processes of a chromatophore are fixed in position in the hypodermis and that the colour changes are brought about by the movements of the pigment granules along fixed pathways, possibly by streaming movements of the cytoplasm. Many chromatophores are syncytial structures containing more than one pigment.



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Crustacean colours and patterns are very diverse, yet in any one species the chromatophore organization is remarkably constant; many different types of chromatophore, each with a specific distribution, form a definite pattern. For example, in the common prawn, *Leander serratus*, which has been used for much experimental work on crustacean colour, the pattern is largely due to large red-yellow chromatophores, which are arranged in bands, and red-white light-reflecting chromatophores, which are sparsely but regularly distributed and are very noticeable when the prawn is on a dark background. The rest of the body is covered with relatively small red-yellow chromatophores. Red, yellow, and white chromatophores are also found on the legs and on the telson and uropods, but these peripheral chromatophores do not always change in phase with those of the body; although they closely resemble the body chromatophores, they are evidently physiologically different.

If prawns are placed in a white dish and are illuminated from above, the white chromatophores expand but the dark chromatophores contract. Conversely, on an illuminated black background, the dark chromatophores expand but the white ones contract. In their natural surroundings however, prawns seldom meet such intense illumination or such monochromatic backgrounds as those encountered in laboratory experiments. Prawns taken from a dredge which has brought them to the surface, and examined at once, show every possible variation in the degree of dispersal of the different chromatophore pigments. So intricate a system must clearly have a complex mechanism of control; for many years nervous control was suspected, even though the most diligent search for nerve endings in chromatophores had failed to reveal them.

### THE DISCOVERY OF THE SINUS-GLAND

Crustacean endocrinology may be said to have begun with the independent demonstration by Perkins (1928) and Koller (1928), working with the shrimps Palaemonetes and Crangon, that interruption of the blood supply to the chromatophores brought about an immediate immobility of the pigments, but that nearby nerve transection was without effect [2, 3]. Chromatophores in denervated areas continued to change when the illumination or background colour was changed. In their search for a blood-borne substance affecting pigment movements they found that by removing the eyes and their stalks they produced dark shrimps with dispersed red pigments; the normal pale colour could be restored if sea-water extracts of the eye-stalk were injected into the eyeless animals. Some years later Hanström [4] showed that the most potent source of pigment-activating substances in the eye-stalk was a small, richly innervated, disc-shaped structure; this he had previously described and called the blood- or sinus-gland, because of its proximity to a blood sinus. For many years following its discovery investigators sought keenly to determine the structure of the sinus-gland, but surprisingly little progress was made. It did not appear to be cellular, though scattered cells have been seen in the sinus-glands of some species [5]. No clear ducts were found, yet lines having the appearance of fine channels were sometimes observed. All investigators agreed that the structure was an extremely simple one, which seemed all the more remarkable when later studies showed that the sinus-glands were apparently concerned in the control of many activities, among them the movements of two retinal pigments, moulting, growth and maturation of the eggs, and the level of blood-sugar. It seemed pertinent to ask: does the sinus-gland produce all the substances which it has been shown to contain, or are these made elsewhere and merely stored in the sinus-gland?

### HORMONES IN THE CENTRAL NERVOUS SYSTEM

While the researches of Hanström were establishing that the sinus-gland was a most potent source of pigment-activating hormone, it had become clear that pigment-activating hormones were also being produced elsewhere. In 1933 Brown [6] found that extracts of the central nervous system contained pigment activators. In 1939 Knowles [7] showed that a white-pigment activator could be extracted from the thoracic region of the central nervous system even when the eye-stalks and their contained sinus-glands had been removed three or four weeks previously. The subsequent search for pigment-activating substances has been described by Brown [8]. Attempts to localize the pigment-activating centre of the nervous system showed that a great activity lies in a transverse commissure, the tritocerebral commissure, so called because of its close phylogenetic relationship with the brain. A closer study of this region showed that a great activity lay not in the commissure itself but in two nerves which arise from the commissure and terminate in muscles near by [Knowles 9, 10]. In



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the prawn Penaeus each nerve is swollen before it reaches the muscle, forming a flat plate which lies alongside a blood-sinus; extracts of this plate were found to have an extremely high pigment-activating potency. Each plate contained a network of fine nerve endings, which apparently did not innervate any end-organ. It seemed reasonable to suggest that they were involved in the liberation of pigment-activating hormones into the adjacent blood-sinuses, and that they might contain these substances as well as control their release. This, the first combined physiological and anatomical demonstration of a neurohumoral system in crustaceans, was soon followed by parallel work on the sinus-gland and other organs.

Many workers studying a moult-inhibiting hormone in crustaceans had reported that the removal of the eye-stalks accelerated moulting changes, but that removal of the sinus-glands alone did not. In 1951 a number of papers were published, all indicating that some of the sinus-gland hormones were not produced in this body but in a cluster of cells previously named the X-organ, and that the substances made in the X-organ cells passed along axon fibres to the sinus-gland. Enami [11], and later Bliss and Welsh [12], showed that the sinus-gland of some crabs was in fact little, if anything, more than the swollen terminations of nerve fibres which originated in the cell-bodies of the X-organ, and that the sinus-gland/X-organ complex was a neurosecretory system bearing certain resemblances to the hypothalamus-pituitary system in chordates. With this discovery a new era in crustacean endocrinology began, and at present a great deal of work is being directed towards the unravelling of the very complex neurosecretory system which undoubtedly exists in crustaceans.

Alexandrowicz has described a number of neuropil-like meshworks of nerve terminations in close proximity to blood-sinuses, and it has been shown that some of these contain physiologically active substances affecting the rate of heart-beat [13, 14]. At present, however, the only structures known to release pigment-activating hormones are the sinus-glands and the post-commissure organs, and the effects of injections of total extracts of these organs suggest that the substances which they contain differ significantly. The injection of sinus-gland extract into an eyeless prawn is followed by a concentration of the small red chromatophores of both the body and the tail. The large red chromatophores are also concentrated, though to a lesser degree, but the white chromatophores are generally unaffected. On the other hand, injection of extract of the post-commissure organs brings about a maximal concentration of the large red chromatophores; little or no concentration of the small red chromatophores; a concentration of the whites; and a maximal dispersal of the red pigments in the tail chromatophores. The differences in the effects of injection of these extracts are very striking (plate II). One produces an almost transparent prawn in which pattern is maximally displayed: the other produces a dark, uniformly coloured animal.

### THE NUMBER OF CHROMACTIVATING HORMONES

Early experiments on different backgrounds showed that the various crustacean pigments have an independence of movement best explained on the basis of the existence of many hormones, each affecting movement of one pigment. It was, however, suggested that the diverse pigment movements might be explained on the basis of the existence of one or a few hormones, supposing that various pigments might be susceptible to the same hormone but that the actual effect depended on the concentration of the hormone in the blood; alternatively, a few hormones might, by being present in various combinations, produce multiple effects. A final decision between the unitary and the multiple hormone theories had to await the separation of different substances each having specific effects on different pigments. Owing to our scanty knowledge of the chemistry of these hormones and the difficulty of obtaining sufficient quantities for analysis, this separation was difficult to effect.

Comparison of the effects of injecting sinus-gland and post-commissure organ extracts suggests that there may be many hormones, and the experiments of Brown and Klotz [15] have shown that by extraction with alcohol two substances from the commissure of Crago can be almost completely separated. One, soluble in alcohol, concentrates body chromatophores but does not affect those of the tail. The other, insoluble in alcohol, darkens both the body and the tail. These and other experiments give reason for believing that more than one hormone affects pigment movements in crustaceans, and that some substances disperse chromatophore pigments and that others concentrate them. This concept of humoral action in crustacean colour change has been supported by recent separation experiments, using paper chromatography and paper electrophoresis, on which the writer and his collaborators are at present engaged [16].



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In a typical paper-electrophoresis experiment sinus-glands or post-commissure organs were extracted with water and the resulting solution was applied to the centre of a paper strip. After electrophoresis the paper was dried and then cut into a number of sections; each portion was extracted with sea-water and the extract was injected into eyeless animals. The resultant colour changes gave an indication of the presence of pigment-activating hormones at various points along the paper strip and showed that the separation of different substances, with specific effects, was possible (figure 18). For example, post-commissure organ extracts have yielded after electrophoresis at *p*H 7·8 (*a*) an electropositive 'A' substance which concentrated all chromatophore pigments; (*b*) an electronegative 'B' substance which concentrated white pigments and the red and yellow pigments of the large red chromatophores, but which expanded other chromatophores of the body and the tail; and (*c*) more mobile substances, each specific for one pigment type. The 'B' substance seemed to be antagonistic to the 'A', and total extracts of the post-commissure organs had predominantly the 'A' or the 'B' effect.

It is by no means certain that all the substances which we have separated by electrophoresis are in fact functional hormones normally present in the blood stream. Indeed, some evidence suggests that the crude extraction methods adopted by earlier workers may have brought into solution substances present in the neurosecretory organs, which when injected had an effect on pigment movements, but which might not under normal conditions have been liberated into the circulation. For example, we have found that extracts of the sinus-glands and post-commissure organs of crustaceans, and of the corpora cardiaca of insects, contain the 'A' substance, active for more than one pigment, which is evidently of relatively high molecular weight. The organ-extracts tested contain a great deal of this substance, and it is tempting to regard it as a functional pigment-activating hormone. Yet if we lay the post-commissure organs in water and electrically stimulate them, we do not afterwards find this substance in the water, though other pigment-activating substances are present. The 'A' substance and the 'B' substance will not pass through a Cellophane membrane, through which other pigment-activating substances, present in total extracts, will pass (figures 19, 21, and 22). Our electrophoresis methods have also revealed mobile substances, each affecting a single pigment, some distance from the point of application to the paper strip, and it seems possible that these are in fact the active blood hormones and that the less mobile substances, with multiple effects on the chromatophore system, may be precursors. It is interesting to note that extracts of the posterior pituitary lobe in mammals, also considered to be a neurosecretory organ, have been shown to contain peptides of relatively low molecular weight having either oxytocic or pressor effects, but not both, and also a protein complex having both pressor and oxytocic activity. It has been suggested that the protein complex is a 'mother-molecule' of the lighter active substances present [17]. Our experiments indicate a similar possibility in the pigment-activating hormone systems of crustaceans.

The possibility that precursor substances are present in the cell-bodies of a neurosecretory system has also been investigated in crustaceans by another method. During his classical studies on the sinus-gland Hanström eliminated the X-organ as a potent source of pigment-activating hormones, because extracts of that portion of the eye-stalk in which it lay had only slight pigment-activating potency. Yet the sinus-gland, so rich in pigment activators, is mainly the swollen tips of fibres which originate in the X-organ, so it is surprising that extracts of the X-organ had so little effect. In fact, fresh extracts of the X-organ alone are without any effect, yet if such extracts are first boiled, or treated with alcohol, and are then injected, a very powerful effect is obtained (figure 20). It is possible that pigment-activating substances are present in the X-organ in a combined form, perhaps bound to some substance and thereby inactivated, and that boiling breaks the bond and frees the active molecule. Such a concept would be in accordance with the different staining reactions of droplets found in the cell-bodies of the X-organ, along the axon fibres, and in the swollen fibre tips of the sinus-gland. It is perhaps not premature to speculate whether the pigment-activating hormones may be stored in an inactive form in the cell-bodies of neurosecretory fibres. Later they may be converted into a form which can bring about pigment movements if it is artificially introduced into the blood stream, even though it does not normally pass into it. This latter substance may be present in the fibres and in their terminations. Finally, enzymatic action may fracture such a prohormone into active substances of low molecular weight, each having specific effects on particular pigments. This concept accords with our



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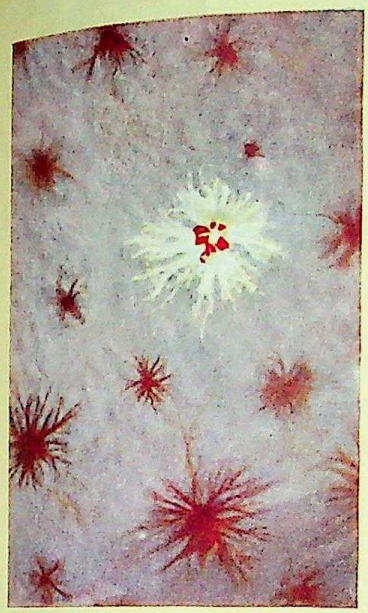
PLATE I



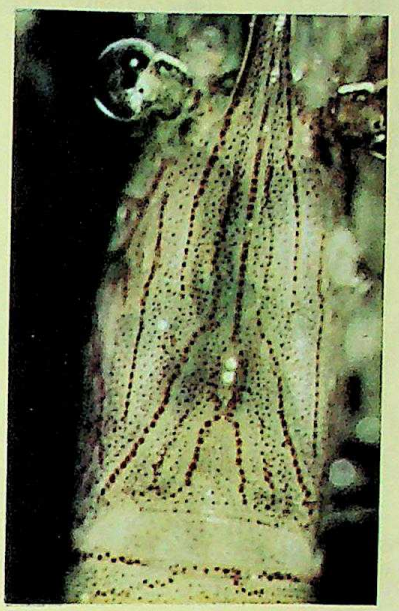


FIGURE 1 (*left*) – *A group of expanded chromatophores (large red, small red, and white).* (× 50)

FIGURE 2 (*above*) – *Some of the chromatophores shown in figure 1, shown after some concentration of the pigments.* (× 50)

FIGURE 3 (*right*) – *A dorsal view of the cephalothorax of* Leander serratus, *illustrating the three chromatophore types shown in figure 1.* (× 4)

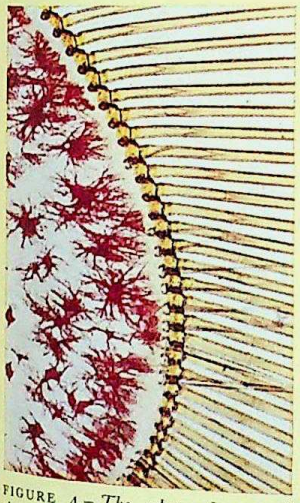


FIGURE 4 – *The edge of one of the uropods, showing all pigments moderately dispersed (cf. figure 12).* (× 25)

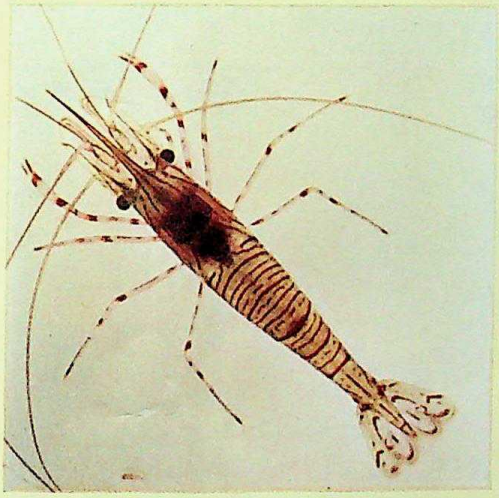


FIGURE 5 – *A common European prawn,* Leander serratus, *that has recently been placed on a dark background. The dark pigments are moderately, though not maximally, expanded. (Natural size)*

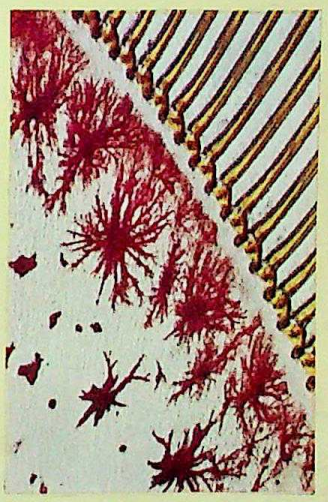


FIGURE 6 – *Edge of a uropod. Pigments dispersed in the peripheral chromatophores, concentrated elsewhere.* (× 50)

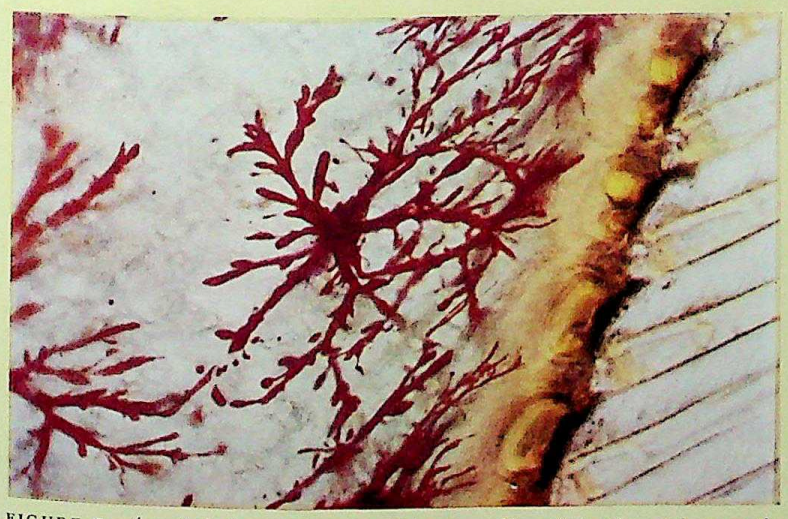


FIGURE 7 – *A uropod chromatophore in which concentration of the pigment has recently begun. The pigment has withdrawn from the finer chromorhizae, which are therefore no longer visible.* (× 200)

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PLATE II

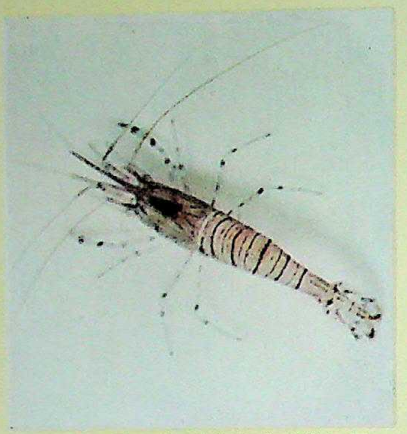


FIGURE 8 – *An eyeless individual which had been injected with sinus-gland extract (one gland in 0·05 ml sea-water).*

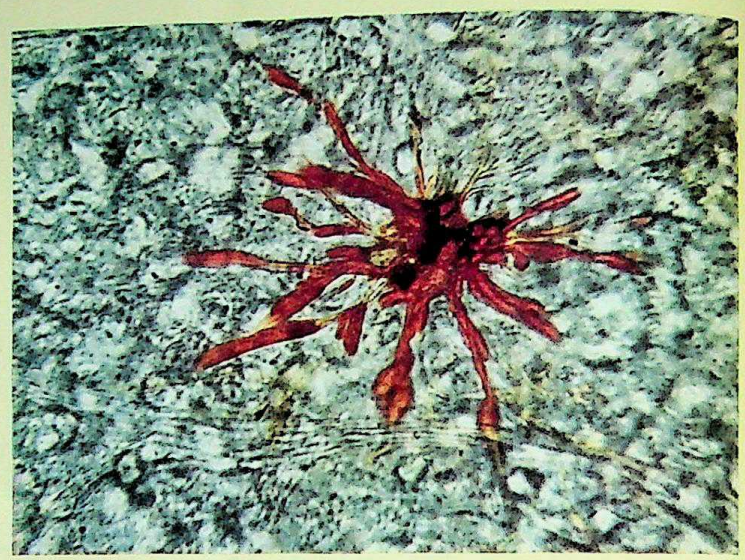
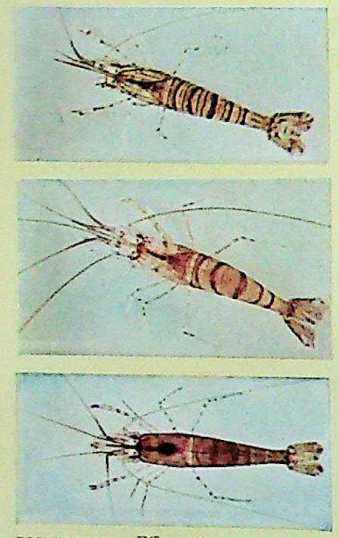
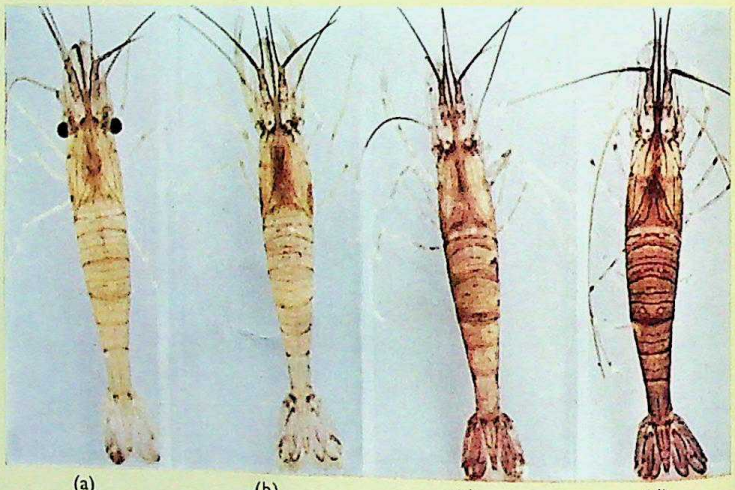


FIGURE 9 – *Uropod chromatophore of an animal injected with sinus-gland extract. The pigments are concentrated sharply and the red pigment has become transformed into a blue one which has left the chromatophore and caused a blueing of the tail.* (× 300)



(a) (b) (c)

FIGURE 10 – *Effects of post-commissure organ extracts.* (a) *Sea-water (control);* (b) *Squilla organ extract;* (c) *Leander organ extract. Both extracts concentrated white and large red chromatophores; Leander extract also dispersed those in tail.*



(a) (b) (c) (d)

FIGURE 11 – *Comparison between the effects of sinus-gland and post-commissure organ extracts.* (a) *Control animal injected with 0·05 ml sea-water;* (b) *injected with 0·05 ml of sea-water extract of two sinus-glands;* (c) *injected with similar extract of two post-commissure organs;* (d) *injected with 0·05 ml sea-water. The eyeless animals had been deprived of their eyes four weeks before injection; the photograph was taken two hours after injection.*

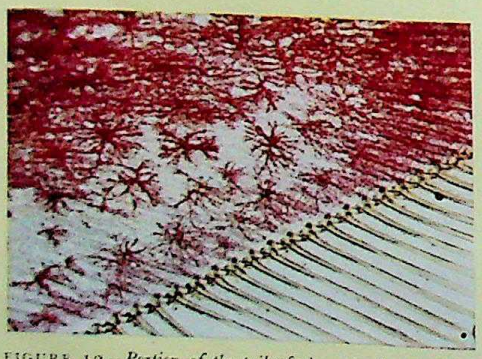
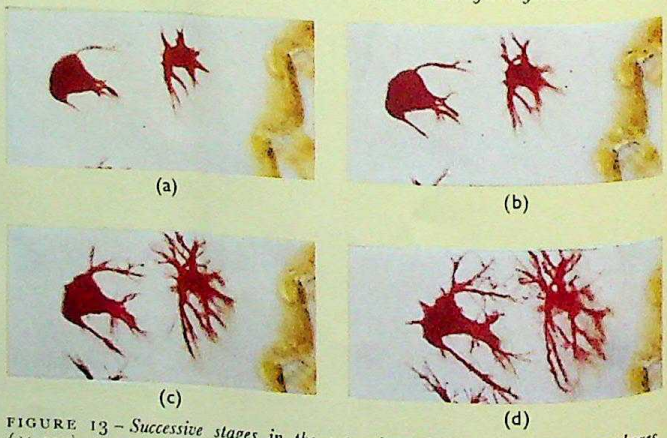


FIGURE 12 – *Portion of the tail of the animal shown at 10(c), showing maximal dispersal of the tail pigments. Compare with figures 4, 6, and 7.* (× 20)



(a) (b) (c) (d)

FIGURE 13 – *Successive stages in the expansion of two uropod chromatophores.* (× 100)

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FIGURE 14 – *The left eye and eyestalk of* Leander serratus *viewed from above a few minutes after it had been detached from the animal. For identification of the visible structures see figure 23. There is some evidence that the disposition and form of the nervous and the neurosecretory structures of the eyestalk differ slightly in the Mediterranean and British forms of the species; this individual was taken at Naples.* (× 30)

FIGURE 15 – *A transverse section through the post-commissure plate of* Penaeus braziliensis, *showing that it lies alongside, and is attached to, the wall of a blood-sinus, and that it contains structures which stain with azocarmine.* (× 150)

FIGURE 16 – *A methylene blue preparation of a portion of the commissure and the base of a post-commissure organ of* Leander serratus. *Fine neurosecretory fibres and droplets in the epineurium are visible.* (× 70)

FIGURE 17 (right) – *A more highly magnified view of a portion of the area shown in figure 16. Peripheral droplets and a central bundle of neurosecretory fibres can be seen.* (× 350)


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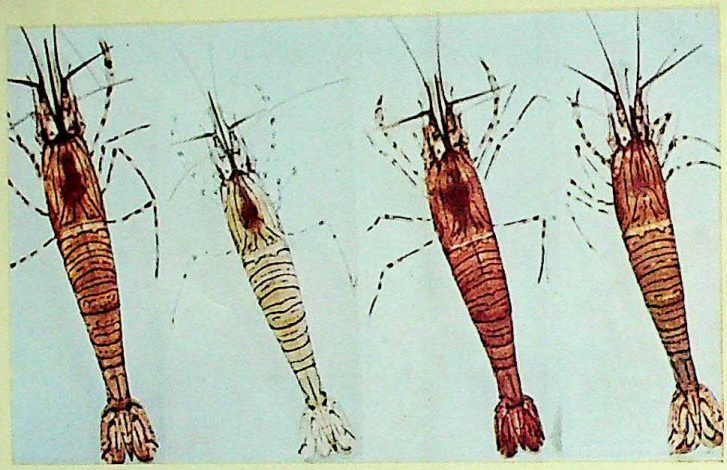
PLATE IV

*Electrophoretic experiment.* 3 *milliamperes.* 16 *hours at* p*H* 7·49

| −5 | −4 | −3 | −2 | −1 | 0 | +1 | +2 | +3 | +4 | +5 |
|---|---|---|---|---|---|---|---|---|---|---|
| Small red chromatophore concentrator | No effect | No effect | No effect | Pigment concentrating substance | Pigment dispersing substance | No effect | Small red chromatophore concentrator | No effect | No effect | No effect |



−2 −1 0 +1

FIGURE 18 – *Electrophoretic separation of pigment-activating substances from an extract containing ten post-commissure organs. Under the conditions of this experiment a substance which dispersed the body and tail chromatophores remained close to the point of application to the paper, slightly displaced towards the anode, but a pigment-concentrating substance which affected large red, small red, and white chromatophores, moved 2–3 cm in the direction of the cathode. Other, more mobile, substances, affecting only single pigments, were also found. Photograph taken* 30 *minutes after injection.*

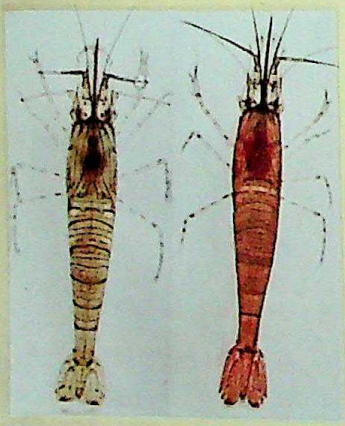
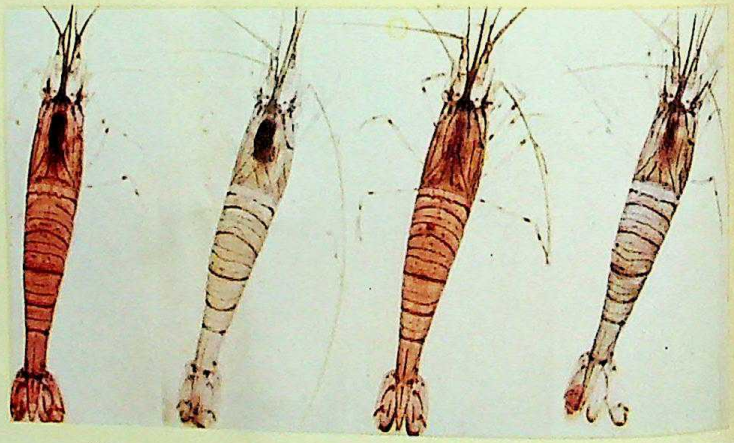


FIGURE 19 – *Separation by dialysis: half an hour before this photograph was taken the left-hand animal received the fraction of a post-commissure extract that had passed through a Cellophane membrane. The right-hand animal received the fraction which did not pass through.*



(a) (b) (c) (d)

FIGURE 20 – *Activation of X-organ extracts.* (a) *Animal injected with X-organ extract;* (b) *animal injected with a boiled extract of X-organ;* (c) *animal injected with untreated X-organ extract;* (d) *animal injected with alcohol-treated X-organ extract.*

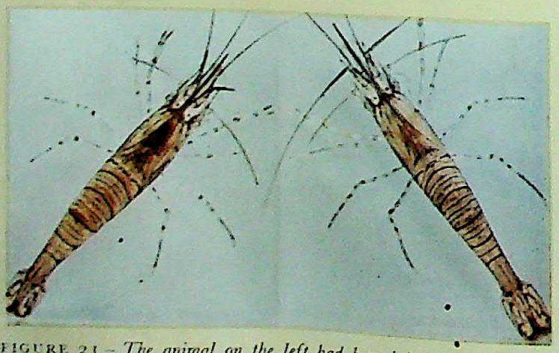


FIGURE 21 – *The animal on the left had been injected half an hour before this photograph was taken with the fraction of a sinus-gland extract that had passed through a Cellophane membrane. The right-hand animal received the fraction which did not pass through.*

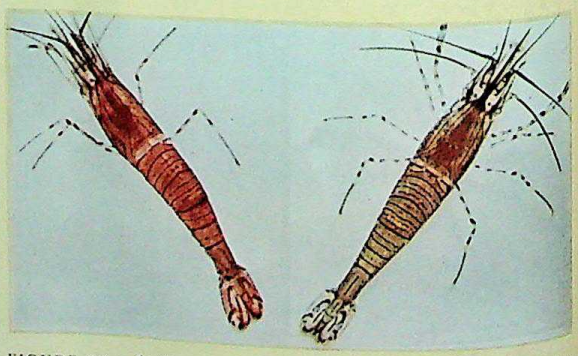


FIGURE 22 – *As figure* 21, *but using an extract of the* −1 *fraction (see figure* 18) *after electrophoresis of a sinus-gland extract. This substance* [illegible] *through a Cellophane membrane.*

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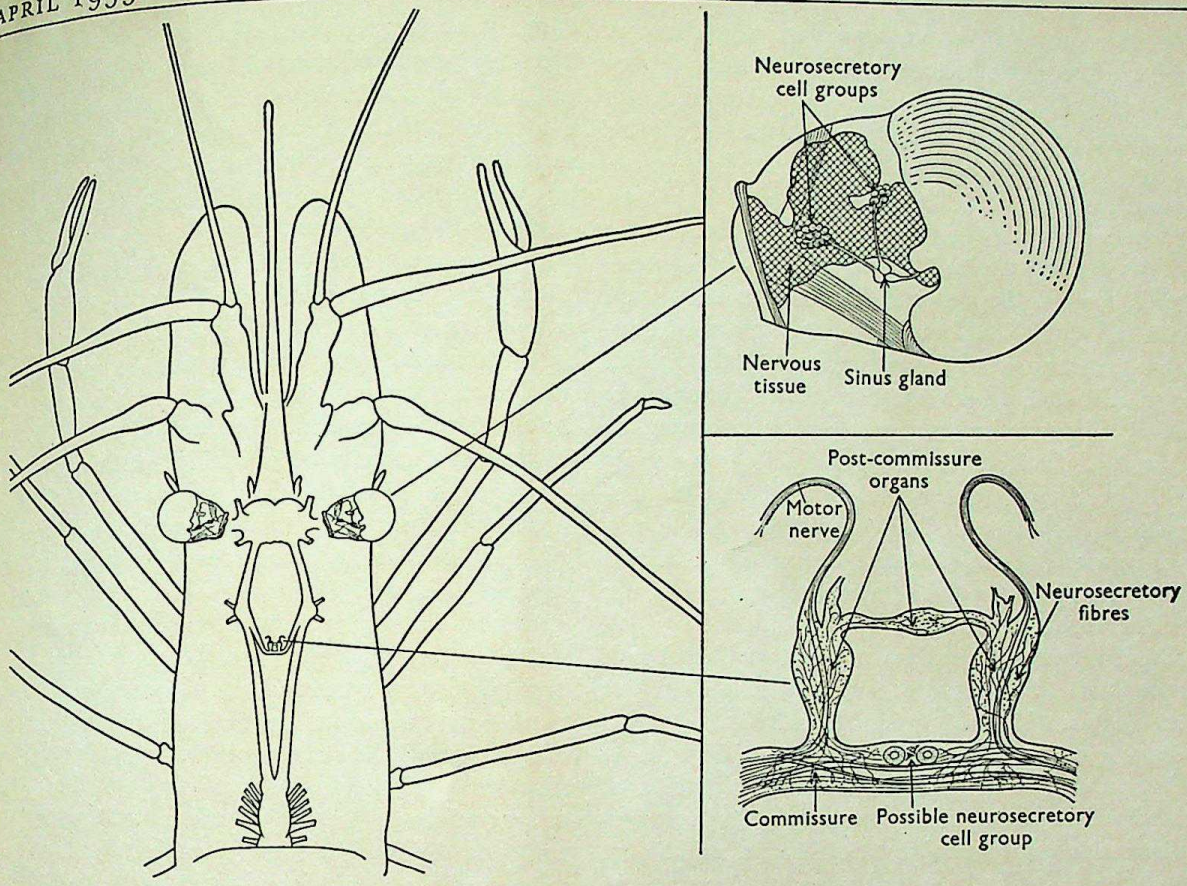


FIGURE 23 – *The position and the general appearance of the neurosecretory systems referred to in the text (compare with plate III). The arrangement of the neurosecretory fibres given is applicable only to* Leander serratus *and differs in other genera. The two neurosecretory cell groups in the eye-stalk have variously been described as X-organs in the literature; the proximal group is the one referred to as the X-organ in the present article.*

present state of knowledge, and it is to be hoped that electrophoresis and other studies may prove or disprove this working hypothesis.

### GENERAL CONCLUSIONS

The electrophoresis and dialysis experiments reported above show that antagonistic hormones may be present in neurosecretory systems. The post-commissure organs seem to contain both body-lightening and body-darkening hormones, which can be separated by physical means. In the sinus-gland of Leander it seems possible that there may be an anatomical separation of different pigment-activating hormones, for in this animal the sinus-gland is formed of three distinct parts, each the terminus of certain distinct nerve fibres, and it is possible to separate these portions and to make extracts of them separately. The portion which receives fibres from the X-organ seems to contain a substance that concentrates white chromatophore pigments, but the remainder of the sinus-gland seems to contain a white-pigment disperser. If this is so, it is likely that different neurosecretory fibres supplying the sinus-gland carry different substances. This raises an interesting problem: how is the controlled release of specific substances from neurohaemal organs effected? Bliss and Welsh have advanced the theory that neurosecretory cells may resemble efferent neurones in so far as they trigger the release of their own products, as an efferent neurone controls the release of the acetylcholine which it contains. However, this interesting theory has not yet received experimental support, though the apparent absence of innervation of the sinus-gland, except by neurosecretory fibres, makes the suggestion a reasonable one. If neurosecretory fibres also act as nerve fibres, in so far as they carry impulses to activate the release of their contained substances, then the resemblances between neurosecretory cells and typical neurones is a close one.

We are then faced with the difficulty of the precise definition of the word neurosecretion, which has been used by different authors in the



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past with more than one meaning. On the one hand we have the histological definition used by Scharrer [18], whose precise and detailed work has done so much to gain acceptance of the general concept of neurosecretion; he has maintained that the term should be used only where evidence of active secretion by nerve cells can be visibly demonstrated by appropriate staining techniques, and in this sense it has been widely used recently. On the other hand we have the functional criterion used by Alexandrowicz, who has regarded fibres which appear to be efferent, yet do not apparently innervate any end-organ, as being, by inference, neurosecretory. It is probably still too early to attempt a final definition of neurosecretion, but it is used in the present article as a convenient term to describe the production and release of blood-borne hormonal substances by the central nervous system of crustaceans.

Such a control mechanism is a combination of nervous and hormonal action, and it is therefore pertinent to look for possible advantages of a neurosecretory process over control by purely nervous or purely hormonal means. A loss of speed in response is inevitable when chromatophores are activated by blood-borne substances instead of by direct innervation as they are in cephalopods, teleost fish, and reptiles, and it is logical to expect that some advantages of neurosecretory control may counterbalance the sacrifice of speed.

Simplicity of anatomical form seems to be one advantage of neurosecretion over direct nervous control. We have seen that very elaborate modifications of colour and pattern are effected in crustaceans by a system of relatively simple structure, though perhaps biochemically complex. Nervous control of such an elaborate colour pattern would have entailed a complex fibre system, but the relatively few fibres in the neurosecretory organs are evidently sufficient to select and release the appropriate hormones to activate the many pigments separately.

Nervous and hormonal control each have their special advantages and limitations. Nervous transmission is well suited to produce localized and immediate changes, such as muscle movements, which must be swift but which generally need not be long maintained. On the other hand, the processes of growth and development necessitate a widespread co-ordination of chemical change which need not be instantaneous but which must often be maintained for a considerable time, and this is effectively managed by the endocrine system. For the production of changes which must be fast and yet also be maintained, it is possible that a combination of nervous and hormonal control would be ideal. The accumulation of hormones in a neurosecretory complex permits slow and prolonged stimulation of the target organs without fatigue of the activating system, and yet the mechanism is sufficiently labile to allow sudden alterations in the intensity or direction of the hormonal release. In this respect neurosecretory control is particularly suitable for the sudden adaptive movements, superimposed on the slow rhythmical and prolonged changes, which characterize the colour-changes of crustaceans.

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# Book reviews

### ANIMAL CYTOLOGY

Animal Cytology and Evolution (*second edition*), *by M. J. D. White. Pp. xiv + 454. Cambridge University Press, London.* 1954. 45*s. net.*

The first edition of Dr White's book appeared in 1945 and was immediately recognized to be the best survey of the structure and behaviour of chromosomes to appear in the English language since Darlington's 'Recent Advances in Cytology' of 1937. He has now put us still further in his debt by revising his book to the extent of an almost complete rewriting. Although his major theme is the connection between chromosome number and structure and the processes of evolution, his book actually covers a somewhat wider field, and provides an introduction to the rapidly advancing studies on the biochemical nature of chromosomes and discussions on the mechanisms of mitotic and meiotic division.

A most valuable feature of the discussion is the breadth of the field from which evidence is drawn. In recent years our knowledge of the evolutionary changes in the chromosomes of Drosophila has achieved a remarkable depth and precision. The author gives a full account not only of the already classical researches of Dobzhansky and his co-workers, but also of the more recent, and perhaps less well known, studies of the Texas group of investigators under Patterson and Stone. But Drosophila is by no means allowed to remain in undisputed possession of the centre of the stage. The author's own extensive and important works on chromosome polymorphism in American grasshoppers adds a most welcome body of data from another group of organisms, and considerably broadens our ideas as to the kinds of changes which evolution may involve. He provides also a remarkably complete survey of studies on evolutionary cytology in all groups throughout the animal kingdom. His book will not only be of extreme value as a work of reference, but expounds in a very clear, and nearly always plausible, fashion the significance to be attached to the various observations, and is therefore a pleasure to read.

C. H. WADDINGTON

### PLANT GROWTH

Growth and Differentiation in Plants, *edited by W. E. Loomis. Pp. viii + 458. Iowa State College Press, Ames.* 1953. 60*s. net.*

This is the second of the monographs, sponsored by the American Society of Plant Physiologists, which have the aim of presentation to a wider, though still technical, public than pure specialists. The sections therefore include mature as well as recent data, and reviews of theories, and even attempts to predict immediate developments. The field covered by the eighteen articles in this volume is extremely wide, ranging from the elongation of a cotton fibre to bio-electric fields, morphogenesis, and diseased growth. Some of the chapters, notably that on growth curves, are of a very elementary standard, others presuppose a good deal more background knowledge; as there are twenty-two authors such variations are only to be expected.

The study of plant growth is still in the phase of simple description, as is readily appreciated by reading the chapter on its 'elementary mathematics,' in which the approximately exponential multiplication of cells in young plants is for some reason called a logarithmic increase. For the most part it is possible to describe the known facts and relevant ideas in simple language, and this the authors have admirably succeeded in doing. By keeping jargon and esoteric terminology firmly within bounds they have achieved a most useful book, that should go far towards realising the aim set for it by its sponsors. It is to be feared that the high price will limit its usefulness in Britain.

W. O. JAMES

### PHYSICAL CHEMISTRY

Physico-Chemical Methods (*fifth edition*), *by Joseph Reilly and William Norman Rae. Two volumes. Pp.* 760 *and* 800 *respectively. Methuen and Company Limited, London.* 1954. £7 10*s. net.*

This book was first published in 1926. In this fifth edition certain chapters of the earlier ones have been revised. A third, supplementary, volume appeared in 1945; this has not so far been revised.

Volume 1 deals with the measurements of length, mass, time, pressure, temperature, and various physical properties of materials, such as specific heat and viscosity. There are also sections describing low- and high-pressure apparatus, glassblowing, and low-temperature techniques. Volume 2 includes chapters on separation processes such as distillation and crystallization, spectrometry, electrical properties of solutions, dielectrics, thermionic vacuum tubes, and radioactivity. The book is very well printed and the figures and diagrams are, in most cases, extremely well drawn and where necessary show clearly details of construction.

In the preface Professor Reilly says: 'The subject matter has become so extensive . . . that it is very difficult for one person to undertake satisfactorily the actual revision.' This must certainly have been true, for the two volumes involve together about 1500 pages, and the weakness of the present edition is that in certain places the information is rather out-of-date. For example, there is a very small section on infra-red spectroscopy, a subject which has been greatly developed since the last edition was published. This subject should certainly be dealt with more fully and in a more up-to-date manner. It seems that in some places changes have been made by adding a further paragraph or two, and a few new references, to an old section. It would have been better if these could have been more suitably fitted into the existing text.

However, though certain parts of the book do not seem to have been revised sufficiently, there is much in both volumes that is extremely valuable, particularly as regards the description and explanation of the more established procedures and determinations. These presentations are most useful; and it is an undoubted advantage to have so much experimental information gathered together in one place.

J. W. LINNETT

### AROMATIC COMPOUNDS

The Structures and Reactions of the Aromatic Compounds, *by G. M. Badger. Pp. xiv + 456. Cambridge University Press, London.* 1954. 63*s. net.*

The fact that such vast numbers of aromatic compounds are known perhaps accounts for the disproportionately large descriptive and preparative treatment accorded to them in most textbooks; the threads of theoretical interpretation are generally loose or tangled, and hidden by the masses of empirical data. There was thus certainly a need for such a book as this, in which the fundamental problems of



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aromatic chemistry as a whole have been stripped of obscuring accretions, plainly stated, and thoroughly discussed. The first two chapters deal with the benzene problem and its theoretical solution, leading to the definition of an aromatic compound as a cyclic compound with a large resonance energy in which all the atoms of the ring take part in a single conjugated system. Dr Badger then considers typical properties of aromatic compounds, including addition reactions, substitution reactions, the Diels-Alder reaction, absorption and fluorescence spectra, photo-oxidation and photo-dimerization, and optical activity. A particularly useful chapter deals with the effects of substituents; here much information scattered throughout the literature is unified.

The book is intended for senior and post-graduate students, but many specialists will welcome it as providing a good conspectus of the whole field of aromatic theory. It is clearly written, well produced, and provided with indexes of subjects and names. One is only too acutely aware of present difficulties of printing and publishing, but as the literature cited goes, in practically all cases, only up to the middle of 1951, and as the preface is dated 1952, the delay in publication was regrettably long.

E. J. HOLMYARD

### THE GROWTH OF CHEMISTRY

From Classical to Modern Chemistry, *by A. J. Berry. Pp. xii + 251. University Press, Cambridge.* 1954. 25*s. net.*

This book captures the reader's interest at the start and holds it throughout. The author begins with an historical discussion of the place of certain theories in chemistry, and makes the valid point that explanations of chemical reactivity in terms of mechanics are never likely to have more than a limited degree of success. Mechanical conceptions, such as those of Baeyer's strain theory, have admittedly been very useful, but they fail in the end to explain the specific properties of individual substances. Even the classical theory of atoms and molecules, essential to the development of nineteenth-century chemistry, ultimately proved inadequate, and Mr Berry reminds us that most physics of the same period was based on the idea of matter as a continuum.

Succeeding chapters deal with vicissitudes of the theory of heat; aspects of classical electricity and electrolysis; physical optics and chemistry; molecular magnitudes; analytical chemistry; chemical formulae; problems of valency, radicals, and constitution; and kinetic chemistry. By thus treating of topics rather than of periods Mr Berry has employed a useful historical perspective, focusing attention upon the trees rather than upon the wood and improving our knowledge of both.

The book emphasizes the influence that physics has exerted upon chemistry, and both physicists and chemists will find in it much to interest them. Like other books from the same press, it is very well produced, and there are full indexes.

E. J. HOLMYARD

### MORPHINE ALKALOIDS

The Chemistry of the Morphine Alkaloids, *by K. W. Bentley, with a foreword by Sir Robert Robinson. Pp.* 433. *Oxford University Press, London.* 1954. 50*s. net.*

It is characteristic of the great extent of research on alkaloids that a book of more than four hundred pages is necessary for a comprehensive description of the results of the chemical investigation of the morphine alkaloids alone. With great experience, the author has included in this monograph a very great number of scientific investigations which have been carried out in recent decades with the aim of elucidating the constitution of morphine and its relatives. These investigations were finally crowned, and in a certain sense also carried to a conclusion, by the synthesis of these compounds.

Subdivision into twenty-eight chapters facilitates survey of the wealth of the material. The history and the beginnings of morphine research; the numerous degradation and rearrangement reactions of the alkaloids; and their biosynthesis and total synthesis *in vitro*, are described in detail. Everybody who wishes to get special information on this group will easily find his way about in this book and will be assisted by many references to original papers.

Bentley's book on the chemistry of the morphine alkaloids seems indispensable for anybody who is interested in this chapter of chemistry. It is a document testifying to the purposeful investigation which many scientists have devoted to these natural substances in recent decades. Sir Robert Robinson, one of the pioneers of morphine-alkaloid research, has written a foreword to the book.

P. KARRER

### CHEMICAL CALCULATIONS

Physicochemical Calculations, *by E. A. Guggenheim and J. E. Prue. Pp. xii + 491. North-Holland Publishing Company, Amsterdam.* 1955. 53*s. net.*

It has long been recognized by teachers of physical chemistry in universities that there is a gap between the experimental work described in original papers and the experiments that can be conducted in a teaching laboratory. Undergraduates should have the opportunity of critically handling data derived from experiments of types that they cannot be expected to observe themselves. They ought to read some original papers, but they cannot cover the whole field in this way. Professor J. H. Wolfenden's *Numerical Problems in Physical Chemistry* (Oxford, 1938) was directed towards filling the gap, by providing numerical data from original papers and leaving the student to compute from them, with the aid of some hints, the relevant quantities. Professor Guggenheim and Dr Prue have produced another solution to the problem; the difference is that the calculation is done in the text. Each of the 171 problems is set out clearly, with references to the original work; the principle of the calculation is briefly indicated (references to standard textbooks might have been included); the calculation is then performed and the result critically commented upon. The selection of problems is broad and representative. The book will be extremely useful in university teaching, but it is a pity that the price is so high.

E. F. CALDIN

### VEGETABLE FATS

Vegetable Fats and Oils, *by E. W. Eckey. Pp. ix + 836. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 132*s. net.*

This volume is the successor to G. S. Jamieson's well-known 'Vegetable Fats and Oils,' first published in 1938. It is planned on different lines, but in some respects the altered arrangement seems to present no improvement. It is a comprehensive and systematic survey of practically all fats of the vegetable kingdom which have so far been examined; of their general characteristics and, where available, their detailed composition; of their specific properties and, where these are of technical interest, their current industrial utilization.

The first seven chapters are general discussions of the chemical and physical nature of vegetable fats, their nutritional aspects, the genesis of fats in



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plants, and a survey of analytical methods. The treatment varies somewhat in excellence and is liable at times to be rather diffuse. The general account of the composition of plant fats is very well done indeed, but their biochemical aspects and their genesis deserve fuller discussion than they have received. The treatment of the manner in which sugar may be converted into fat in the seeds of plants, in particular, relates mostly to old work and takes no account of several recent contributions.

The greater part of the book, as in its predecessor, is rightly devoted to descriptions of individual plant fats. Jamieson arranged these alphabetically, first dividing the vegetable fats into the then conventional rough groupings of non-drying, semi-drying, and drying oils. The latter divisions are admittedly not very serviceable, and it is more satisfactory to group fats according to their chief component acids. It is then seen that the seed fats of a particular plant family, or of several plant families, may frequently have common features. Eckey, however, has gone further and has classified the vegetable fats strictly according to the botanical orders to which the plants belong. In the present state of knowledge this seems to confuse rather than to simplify the apparent relations of plant fat composition with botanical sources. For example, the seed fats of the families Rosaceae, Euphorbiaceae, and Cucurbitaceae have certain broad features which make their consideration together not unreasonable; yet these families fall in three different orders, Rosales, Geraniales, and Campanulales respectively. Conversely, in the Geraniales are included not only Euphorbiaceae (species of which may yield seed fats rich in linolenic, elaeostearic, ricinoleic, or other acids) but Linaceae (linseed oil), Rutaceae (citrus oils, rich in palmitic as well as linoleic acid), and Meliaceae (seed fats often rich in stearic as well as other acids). The readers for whom this book is primarily intended will be more interested in the composition of the fats than their ultimate botanical origin, and, despite the index, they might have preferred a treatment based more simply on the constitutive similarities of specific fats.

There is much in this volume which merits commendation: it is designedly written with the needs of American readers primarily in mind, but it will be of interest to wider circles. It is well printed, clearly arranged, and adequately indexed.

T. P. HILDITCH

### INFRA-RED SPECTROSCOPY

The Infra-red Spectra of Complex Molecules, *by L. J. Bellamy. Pp. xv + 321. Methuen and Company Limited, London.* 1954. 35*s. net.*

In spite of the remarkable and rapid advance of infra-red spectroscopy into physical and organic chemistry few books are yet available for the guidance of those research workers who now have to use the technique with little or no previous training in it or knowledge of the relevant theory. Any text of this kind will therefore command a wide interest. This book deals very thoroughly with one particular aspect of the study of complex molecules, namely structural diagnosis by means of the infra-red absorption spectrum. The method is based upon the fact that certain atomic groupings give rise to vibration frequencies of about the same magnitude in different molecules, regardless of the rest of the molecular structure. Such groups may therefore be identified by absorption bands which appear at characteristic positions. Since absorption spectra can now be measured easily using very small quantities of material, there is a potentially powerful method for the study of natural and synthetic products, the success of which has already been established in some spectacular cases.

The author has presented a comprehensive survey and summary of all the significant correlations so far discovered, detailed attention being given to different types of carbon-hydrogen bond in hydrocarbons, to the variety of carbonyl groups and of nitrogen-hydrogen bonds, and to ring systems of various sorts. Anyone concerned directly with this field will find this review, with its exhaustive bibliography, a most valuable work of reference. The author has also tried to indicate the circumstances in which the correlation rules are unreliable. This is a very important point, since there may at present be a tendency to apply this diagnostic weapon without due caution. Many factors, some of which are not yet fully understood, may cause displacement of the key bands, and the experienced worker will bear this in mind when analysing his results. In fact, some may regard with a degree of uncertainty a few of the interpretations used by the author in his illustrative diagrams. One of the difficulties arises because the intrinsic intensity of a given group vibrational band may alter considerably from one molecule to another, and there has hitherto been little constructive study of this matter.

This book, although rather expensive for its size, is a valuable collection of the relevant information, and, although too exhaustive for the student reader, will be very useful for the specialist or industrial organic chemist.

H. W. THOMPSON

### ISOTOPE GEOLOGY

Isotope Geology, *by K. Rankama. Pp. xvi + 535. Pergamon Press Limited, London.* 1954. 75*s. net.*

Since the war the applications of nuclear physics to geology have extended and multiplied so rapidly that the subject has become a trackless jungle where the student's only guides are the often contradictory original papers. Professor Rankama has taken this great mass of information and reduced it to order. The first 150 pages give an elementary review of the relevant properties of stable and radioactive nuclei. This is followed by about 300 pages in which each element is considered in turn. Finally there is a bibliography of about 1300 references, including some as recent as 1954.

The subjects treated include the determinations of the ages of rocks, using, among other methods, those depending on uranium, lead, strontium, rubidium, potassium, argon, and carbon; the age of the earth's crust and of the elements, palaeo-temperatures from $O^{18}:O^{16}$ ratios; and the biological fractionation of sulphur, and its bearings on the date of appearance of bacteria. The approach is that of a geochemist rather than a geologist, and hardly touches the problem of integrating this new body of knowledge with the rest of geology. Probably the author was wise in this—what was needed was a critical compilation and review, and this he has provided.

The printing, production, and paper of the book are of the usual high standard of the Pergamon Press. The reader should not be deterred by 'exactization' and 'synoptical' in the first paragraph of the preface; the English of the rest of the book is excellent.

E. C. BULLARD

### GEOCHEMISTRY

Geochemistry, *by the late V. M. Goldschmidt, edited by Alex Muir. Pp. 730. Oxford University Press, London.* 1954. 63*s. net.*

The author's modest preface to this book, which begins: 'It is, of course,



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very difficult for any single author to cover the whole field of geochemistry', tends to conceal a much more significant fact—that few people have made such a major contribution to any subject, even in its infancy, as Goldschmidt made to the field which will always be associated with his name. The book is in the nature of an unfinished symphony, for Goldschmidt was unable to finish it before his death. The editor must be congratulated on a remarkable achievement in piecing together the intended text of the book, so far as it had been completed, previous publications by the author necessary to round off certain sections, and other material, sometimes written up from notes and sometimes contributed by those in touch with Goldschmidt's work. One might have expected such a compilation to lack coherence, yet not only is the book extremely coherent, but it is readable and conveys the same sense of fascination as came from listening to, or conversing with, the author himself. For Goldschmidt could call upon his encyclopaedic knowledge to talk to mineralogist, chemist, geologist, crystallographer, or metallurgist on equal terms. The whole progress of modern chemistry has been profoundly affected by the work recorded here and by the theory and philosophy which Goldschmidt built upon it.

The detailed geochemistry of the various elements is largely as he wrote it; the more theoretical part is somewhat more synthetic. It is best that it should be this way, for the theories he propounded may naturally be modified in the light of later experiments and discoveries. The book, however, will stand as a monumental base for the subject, presenting, as he would have liked to see it, both the author's own contribution and the contemporary developments which they inspired.

F. M. BREWER

### COAL

Coal, *by Wilfrid Francis. Pp. viii + 567. Edward Arnold (Publishers) Limited, London.* 1954. 84*s. net.*

In 1918 Marie Stopes and R. V. Wheeler published a classic monograph on the constitution of coal. In less than 50 pages they reviewed critically the meagre existing knowledge of the subject and indicated plainly the great field for study. In the thirty-six years that have elapsed since then nothing comparable in scope to this new book has been published. It is the direct heir of the famous monograph, and it is fitting that one of Wheeler's men should have undertaken for his own generation the great task of compiling a comprehensive and up-to-date survey of work bearing on the origin and constitution of coal. In doing this Dr Francis has achieved a large measure of success, and his work should be received with unreserved gratitude. In a short notice of this kind it would perhaps be fairest to leave it at that and to commend to all serious students of coal science an invaluable book of reference.

And yet, to the informed reader, there are steadily recurring questions to which the book provides no answers. Where have we got to in our attempts to elucidate the complexities of coal constitution ? Which of the many lines of attack have proved the most fruitful ? Where should new research be concentrated ? These are the problems that face the research worker today, and a critical judgment on them, though it would undoubtedly have introduced a controversial element, would have added greatly to the value of the book. This could profitably have been attempted in a concluding chapter. Apart from this lack of a critical analysis of the vast canvas displayed, the only other major criticism of the book must be of its inadequate treatment of physical researches on coal, which in recent years have so greatly added to our knowledge of coal structure. The short chapter dealing with this does much less than justice to the versatility, ingenuity, scope, and potentiality of the physicist's contribution. The book would have been strengthened by a collaborator here.

It would be churlish, however, to close on a note of criticism. Clearly this is an outstanding book and a remarkable achievement on the part of one man. It is beautifully printed and superbly illustrated.

A. M. WANDLESS

### MEMOIRS

Obituary Notices of Fellows of The Royal Society, *Volume* 9. *Pp.* 264. *The Royal Society, London.* 1954. 30*s. net.*

In a recent review in these columns Sir Henry Dale referred to the potential value to future scientific historians of intimate reminiscences of men who seem likely to retain their important stature in the longer perspective of future appraisement. Outstanding among such reminiscences are the official obituary notices of Fellows of the Royal Society, now published annually by the Society as a separate volume. Prepared with most meticulous care and from every available source, these notices will certainly be invaluable in the future, when documents are lost and living memory no longer there, but they also have a present value additional to their immediate purpose of paying tribute to great scientists whose work is done. Within them will be found much that is already of historical interest, for in the very nature of things much of a man's most original work is done comparatively early in life. Many of the notices contain concise and clear accounts of discoveries and theories which were revolutionary in their day but have already gained general acceptance. To take at random an example from the present volume, Sir Henry Tizard's obituary of N. V. Sidgwick contains, apart from a wealth of personal detail, a most interesting account of the development of the electronic theory of valency.

The importance as works of reference of these excellently produced volumes deserves to be much more widely appreciated than it is.

TREVOR I. WILLIAMS

### HISTORY OF SCIENCE

Science in History, *by J. D. Bernal. Pp. xxiv + 967. C. A. Watts and Company Limited, London.* 1954. 42*s. net.*

This book is an attempt to describe and interpret the relations between the development of science and that of other aspects of human history. Professor Bernal's enterprise is a great one—so great that one may ask whether it can be profitably undertaken. To do it well the author should know all science and all history—and not merely the events of history but the changing attitude of man towards his world. To say that Professor Bernal does not know all this is no dispraise, but the limitations of human faculty have made it necessary that he should rely, not on the ultimate facts of history and of science, but on the generalizations and conclusions of other men. These are often controversial, but in a book of this scope the argument and counter-argument are necessarily omitted and we have to rely very largely upon the author's judgment of controversies and his selection of generalizations on which to base his arguments. Professor Bernal cannot,



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however, be called an unbiased investigator: he starts with strong political views of the extreme left wing and also with the conviction that the content of religion is nonsense. He can, therefore, be accepted as a guide only by those who share such views, and so his book is not one to be used as an authority by those new to the subject. Nevertheless, the whole of the text is of great interest. Professor Bernal brings a keen mind to bear on the relations of science and history, and no one can read the book without finding a hundred statements controversial enough to provoke new trains of thought. It is, I believe, the first book of its kind, and the man who breaks new ground earns our gratitude, even though he bring in weeds with his harvest. F. SHERWOOD TAYLOR

### INDUSTRIAL HISTORY

A Merseyside Town in the Industrial Revolution: St Helens 1750–1900, *by T. C. Barker and J. R. Harris. Pp. xviii + 508. University Press of Liverpool, Liverpool.* 1954. 30*s. net.*

This well-documented story of the growth of a hamlet to an important industrial town of some 85 000 inhabitants is primarily a social and economic study. It contains, however, a great deal of information of value to the serious student of the history of the scientific industries, especially the chemical industry. Of particular interest is the way in which the siting and development of industry can be affected, perhaps decisively, by what may seem to be in themselves trifling factors. Thus the neglect of the alkali manufacturers, in 1845, to take an opportunity of having the ton legally as well as practically defined—for the purpose of carrying their raw materials on the Sankey Canal—as 3360 pounds (the long ton) instead of 2240 pounds (the imperial ton), was in large measure responsible for the ultimate eclipse of St Helens by Widnes as a chemical manufacturing centre.

The technical development of the glass industry, for which St Helens is world famous, is described in some detail, as is that of the once flourishing copper-smelting works. Though brief, the account of the long struggle between the ammonia-soda and the Leblanc process, culminating in the formation of the United Alkali Company Limited, in 1890, contains a great deal of useful detail not otherwise easily obtainable.

TREVOR I. WILLIAMS

### HISTORY OF MATHEMATICS

The Mathematical Practitioners of Tudor and Stuart England, *by E. G. R. Taylor, with a foreword by Sir Harold Spencer Jones. Pp. xi + 443. Cambridge University Press, London, for the Institute of Navigation.* 1954. 55*s. net.*

The practitioners were the instrument makers, surveyors, teachers of mathematical arts and of navigation, and others who were active in science, but not great scientists. For the period 1485–1715 Professor Taylor has compiled biographical notes on 582 persons and described 628 of the books they wrote. She has thereby rendered a signal service to bibliographers and historians of science: the greater part of the material has been newly collected from original sources, but even the small amount previously available was scattered through some dozens of works of reference. This book initiates a revolution in the historiography of sixteenth- and seventeenth-century science; the stage has now been peopled with the numerous minor characters without whom the principals could not have worked and cannot now be properly understood.

In addition to the notes, the author has provided a continuous narrative describing the evolution and progress of the practitioners and showing the importance of their contributions. The general reader will find it illuminating as a new perspective, the specialist will benefit from the large amount of historical research which is now presented for the first time. D. J. PRICE

### EARLY MEDICAL BOOKS

A Catalogue of Incunabula in the Wellcome Historical Medical Library, *by F. N. L. Poynter. Pp. xv + 160. Oxford University Press, London, for the Wellcome Historical Medical Museum.* 1954. 50*s. net.*

Incunabula are books printed when printing was in its swaddling-clothes, that is to say from the time of its invention, about 1450, up to the end of the fifteenth century. A surprisingly large number of books were in fact printed during this period, and the present catalogue lists no fewer than 610 items—though some of the items are merely different editions of the same work. The late Sir Henry Wellcome had the 'ambition to obtain wherever possible the first, or at least a very early printed, edition of every medical work of any consequence'; his measure of success may be judged by the fact that the collection here described contains 117 items not found at the British Museum. Not all the books mentioned are wholly devoted to medicine, for at that time the lines of demarcation between various branches of learning were not sharply defined. Thus the Bible and the 'Nuremberg Chronicle' find place with Avicenna's 'Canon of Medicine' and Gilinus' *De morbo gallico*, and Ovid's *De arte amandi* with Galen's *Therapeutica*.

In his catalogue, Mr. Poynter gives references to the standard bibliographies of incunabula, but adds such details about the Wellcome copies as provenance, signatures, manuscript notes, early bindings, former ownership, and immediate provenance. He also provides indexes of names, subjects, marks of ownership, printers, countries and towns, and chronology. There are twelve plates. In helping to fulfil Sir Henry's object of 'making available to students of the history of medicine the original texts which are the basis of their study', this catalogue should find a place in every medical and scientific reference library. E. J. HOLMYARD

### CARTESIAN GEOMETRY

The Geometry of René Descartes (translated by D. E. Smith and M. L. Smith). *Pp. 243. Dover Publications Inc., New York.* 1954. $1.50 *paper;* $2.95 *cloth.*

Cartesian geometry and Cartesian co-ordinates are terms with which the schoolboy student of mathematics is early made familiar, and serve to remind us of the prime importance of the *Géométrie* of René Descartes, in which the analytical method was first systematically developed. The treatise first came out in 1637, as, in a way, a supplement to the *Discours de la Méthode*, not only bound up with, but paged as part of, that book; it did not appear as a separate work until 1664. The early French editions are very rare, and Latin, in which less rare editions appeared, is not today a language familiar to the average student of the history of science.

In 1925 the Open Court Publishing Company, with the student's need in view, brought out a facsimile of the original edition of 1637, with an English translation, by David Eugene Smith, the well-known historian of mathematics, and Marcia L. Latham, printed on pages opposite the text. This is of service to those to whom the French, in



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an orthography somewhat different from that now in use, might offer difficulty. The edition now issued by Dover Publications appears to be a photographic copy, in a somewhat reduced size, of the Open Court publication, but there is no reference to this, that the reviewer can find, except that the Open Court Company is named in the *Preface*, which, as it appears in photographic reproduction of the original preface, could scarcely be avoided. This lack of acknowledgment of a previous publication appears to be a policy of Dover Publications: their recent reissue of Newton's *Opticks*, with a foreword by Einstein and an introduction by E. T. Whittaker, was a reprint of the edition brought out in 1931 by G. Bell and Son, for which the preliminary articles were originally written; but there was no reference to this fact. No doubt the legal formalities have been observed, but the practice of reprinting without acknowledgment is not a very gracious one.

The copy before us is paper covered and held together by stabbed wires, which no doubt is one factor making for the cheapness that has been achieved. Of the 'higher priced cloth edition' at $2.95, to which reference is made on the cover, no copy has been furnished.

E. N. DA C. ANDRADE

PHARMACEUTICAL CODEX

The British Pharmaceutical Codex 1954. *Pp. xxxii + 1340. The Pharmaceutical Press, London.* 1954. 63*s. net.*

The appearance of a new edition of the British Pharmaceutical Codex only five years after the preceding one is an indication of the present high rate of change in medicinal treatment, for the previous intervals were all of more than ten years. The functions of the Codex remain unchanged. While primarily a book of reference for those prescribing and those dispensing medicine, it is secondarily a book of standards for substances not included in the British Pharmacopoeia. Like the Pharmacopoeia, the Codex is prepared by a number of committees, each concerned with one aspect of pharmaceutical work. The result therefore represents a mass of very valuable information, because it is selected with care by those familiar with both the theory and the practice of their subject.

The book is four hundred pages shorter than the 1934 Codex, and it is to be noted that 'the pressure on space exerted by new drugs of undoubted value is such that tradition or sentiment cannot be counted an adequate reason for inclusion.' This must have been a painful decision for many of those who helped in the compilation. The monographs with their structural formulae are admirably written and beautifully printed. The Pharmaceutical Society is to be warmly congratulated on this fine work.

J. H. BURN

PHOTOGRAPHIC THEORY

The Theory of the Photographic Process (*revised edition*), *by C. E. K. Mees. Pp.* 1133. *The Macmillan Company, New York.* 1954. $21.50 *net.*

Under the general editorship of the vice-president in charge of research of the Eastman Kodak Company, an outstanding group from the Kodak laboratories at Rochester and at Harrow has produced a unique account of the photographic process in this volume of over a thousand pages. The first edition, published in 1942, quickly established itself as a critical and authoritative guide to the subject. Advances made since then, many of them resulting from researches in the Kodak laboratories, have necessitated extensive revision of the text and the rewriting of many of the chapters. New chapters have been added on the photographic effects of charged particles and of X-rays. Part III, on optical sensitizing, provides a particularly valuable account of this field and incorporates much new material.

The photographic process will provide fruitful subjects for research for many years to come. Chemists and physicists who are led to photographic research by the stimulating references to unsolved problems will join all who are concerned with the theory of the photographic process in acknowledging indebtedness to Dr Mees for the policy which has allowed members of his staff to engage in such a large proportion of fundamental research, to publish the scientific results of their investigations, and to present their considered views in this comprehensive volume.

J. W. MITCHELL

# Some books received

(*Note.* Mention of a book on these pages does not preclude subsequent review.)

ASTRONOMY

Meteor Astronomy, *by A. C. B. Lovell. Pp. xiv + 463. Oxford University Press, London.* 1954. 60*s. net.*

BIOLOGY

Aspects of Deep Sea Biology, *by N. B. Marshall. Pp.* 380. *Hutchinson's Scientific and Technical Publications, London.* 1954. 35*s. net.*

Biology of Deserts, *edited by J. L. Cloudsley-Thompson. Pp.* 224. *Institute of Biology, London.* 1954. 14*s. net.*

Einführung in die Biologische Registriertechnik, *by H. Klensch. Pp. x +* 222. *Georg Thieme Verlag, Stuttgart.* 1954. *D.M.* 33.

The Genetics of *Paramecium Aurelia, by G. H. Beale. Pp.* 179. *Cambridge University Press, London.* 1954. 12*s.* 6*d. net.*

The Natural Regulation of Animal Numbers, *by D. Lack. Pp.* 343. *Oxford University Press, London.* 1954. 35*s. net.*

Probleme und Beispiele Biologischer Regelung, *by R. Wagner. Pp.* 219. *Georg Thieme Verlag, Stuttgart.* 1954. *D.M.* 29.70.

CHEMISTRY

The Chemistry of Lipids of Biochemical Significance, *by J. A. Lovern. Pp. xiii +* 132. *Methuen and Company Limited, London.* 1955. 8*s.* 6*d. net.*

Atomic and Free Radical Reactions, *Volumes* 1 *and* 2 (*second edition*), *by E. W. R. Steacie. Pp. x +* 901. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. £11 4*s. net.*

The Elements of Chromatography, *by T. I. Williams. Pp.* 90. *Blackie and Son Limited, Glasgow.* 1954. 9*s.* 6*d. net.*

Émulsions, Mousses, Détersion, *by P. Cor. Pp. xvi +* 129. *Dunod, Paris.* 1955. *Fcs* 980 *net.*

Geochemie seltener und nur in Spuren vorhandener chemischer Elemente im



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Boden, *by A. P. Winogradow. Pp.* 249. *Akademie-Verlag, Berlin.* 1954. *D.M.* 23.

Ephraim's Inorganic Chemistry (*sixth edition*), *by P. C. L. Thorne and E. R. Roberts. Pp. xii* + 956. *Oliver and Boyd Limited, Edinburgh.* 1954. 35*s. net.*

Isotopic Gas Analysis for Biochemists, *by R. F. Glascock. Pp. viii* + 247. *Academic Press Inc., New York; Academic Books Limited, London.* 1954. $5.80.

Manuel Technique d'Analyse Microbiologique du Sol, *by J. Pochon. Pp. viii* + 123. *Masson et Cie, Paris.* 1954. *Fcs* 750 *net.*

Mass Spectrometry, *by A. J. B. Robertson. Pp.* 135. *John Wiley and Sons Inc., New York; Methuen and Company Limited, London.* 1954. 8*s.* 6*d. net.*

Solvent Properties of Amphiphilic Compounds, *by P. A. Winsor. Pp. ix* + 207. *Butterworths Scientific Publications, London.* 1954. 40*s. net.*

Chemistry and Biology of Pteridines (a Ciba Foundation Symposium), *edited by G. E. W. Wolstenholme and Margaret P. Cameron. Pp. xiv* + 425. *J. and A. Churchill Limited, London.* 1954. 42*s. net.*

GENERAL

La Cybernétique; "Du Cerveau Humain aux Cervaux Artificiels," *by P. Cossa. Pp.* 98. *Masson et Cie, Paris.* 1955. *Fcs* 525 *net.*

English for the Scientist (*fourth edition*), *by C. Duval. Pp.* 96. *Centre National de la Recherche Scientifique, Paris.* 1954. *Fcs* 450 *net.*

First Voyage, *by John Guyther. Pp.* 208. *Andrew Melrose Limited, London.* 1954. 16*s. net.*

The Kinetic Basis of Molecular Biology, *by F. H. Johnson, H. Eyring, and M. J. Polissar. Pp. vii* + 874. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 120*s. net.*

Psychology as the Study of Behaviour (an Inaugural Lecture), *by O. L. Zangwill. Pp.* 36. *Cambridge University Press, London.* 1954. 2*s.* 6*d. net.*

Radioisotope Conference 1954. Volume II: Physical Sciences and Industrial Applications, *edited by J. E. Johnston, R. A. Faires, and R. J. Millett. Pp. ix* + 223. *Butterworths Scientific Publications, London.* 1954. 45*s. net.*

Scientific Books, Libraries and Collectors, *by J. L. Thornton and R. I. J. Tully. Pp. x* + 288. *The Library Association, London.* 1954. 24*s. net.*

The Technical Report: Its Preparation and Use in Industry and Government, *edited by B. H. Weil. Pp. xii* + 485. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 96*s. net.*

United Kingdom Postgraduate Awards, 1954–5. *Pp.* 117. *The Association of Universities of the British Commonwealth, London.* 1954. *N.p.*

GEOLOGY

General Principles of Geology, *by J. F. Kirkaldy. Pp.* 327. *Hutchinson's Scientific and Technical Publications, London.* 1954. 25*s. net.*

Geology of Petroleum, *by A. I. Levorsen. Pp. x* + 703. *W. H. Freeman and Company, California; Bailey Bros. and Swinfen Limited, London.* 1954. 68*s. net.*

MATHEMATICS

A Budget of Paradoxes, *by Augustus de Morgan* (with a new introduction by E. Nagel). *Pp.* 387. *Dover Publications Inc., New York.* 1954. $4.95 *cloth net.*

The Psychology of Invention in the Mathematical Field, *by J. Hadamard. Pp. xiii* + 145. *Dover Publications Inc., New York.* 1954. $2.50 *cloth;* $1.25 *paper net.*

MEDICINE

Fluoridation as a Public Health Measure, *edited by J. H. Shaw. Pp. v* + 232. *A.A.A.S., Washington, D.C.; Bailey Bros. and Swinfen Limited, London.* 1954. 40*s. net.*

The National Formulary 1955. *Pp.* 210. *The Pharmaceutical Press, London.* 1955. 5*s. ordinary;* 8*s. interleaved net.*

Serological Approaches to Studies of Protein Structure and Metabolism, *edited by W. H. Cole. Pp. xi* + 97. *Rutgers University Press, New Jersey.* 1954. $2 *net.*

Trattato di Istologia, *Volumes* 1 *and* 2, *by Giuseppe Levi. Pp. xvi* + 1171. *Unione Tipografico-Editrice Torinese, Turin.* 1954. *L.* 12 000.

Dust is Dangerous, *by C. N. Davies. Pp. xvii* + 116. *Faber and Faber Limited, London.* 1954. 21*s. net.*

Mensche und Mikrobe; Abenteuer im Unsichtbaren, *by F. Bolle. Pp.* 396. *Safari-Verlag, Berlin.* 1954. *D.M.* 16.80.

Strahlendosis und Strahlenwirkung, *by B. Rajewsky. Pp.* 112. *Georg Thieme Verlag, Stuttgart.* 1954. *D.M.* 11.

PHILOSOPHY

The Sources of Eddington's Philosophy, *by H. Dingle. Pp.* 64. *Cambridge University Press, London.* 1954. 3*s.* 6*d. net.*

Vom Sein und Sollen des Menschen, *by H. Muckermann. Pp.* 344. *Westliche Berliner Verlagsgesellschaft Heeneman KG, Berlin-Wilmersdorf.* 1954. *D.M.* 22.50.

Die Welt sieht anders aus unser Weg ins Atomzeitalter, *by W. D. Müller. Pp.* 287. *R. Oldenbourg, Munich.* 1954. *D.M.* 15.80.

PHYSICS

Advanced Level Examples in Physics, *by R. V. Johns and W. F. Ware. Pp. viii* + 346. *Macmillan and Company Limited, London.* 1954. 16*s. net.*

Analysis of Deformation, *Volume* 2, *by K. Swainger. Pp. xxxvi* + 365. *Chapman and Hall Limited, London.* 1954. 70*s. net.*

Dynamical Theory of Crystal Lattices, *by Max Born and Kun Huang. Pp. viii* + 420. *Oxford University Press, London.* 1954. 50*s. net.*

The Physics of Particle Size Analysis (Conference arranged by the Institute of Physics, from 6th to 9th April, 1954), *British Journal of Applied Physics Supplement No.* 3. *Pp. vi* + 218. *The Institute of Physics, London.* 1954. 35*s. net.*

Introduction to Atomic and Nuclear Physics (*third edition*), *by Henry Semat. Pp. xii* + 561. *Chapman and Hall Limited, London.* 1954. 50*s. net.*

TECHNOLOGY

Fiberglas Reinforced Plastics, *by R. H. Sonneborn. Pp. xii* + 244. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 36*s. net.*

Successful Commercial Chemical Development, *edited by H. M. Corley. Pp. xxv* + 374. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 62*s. net.*

ZOOLOGY

The Evolution of an Insect Society, *by D. Wragge Morley. Pp.* 215. *George Allen and Unwin Limited, London.* 1954. 18*s. net.*



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# Notes on contributors

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Was born in Ottawa in 1915 and was educated at Radley and at Oriel College, Oxford, where he specialized in zoology and comparative anatomy. In 1937 he held the Oxford University Naples Scholarship and studied the endocrinology of lampreys and crustaceans at the *Stazione Zoologica*, Naples. There he began studies on neurosecretion which were interrupted by the war, but which he was afterwards able to recommence in Bermuda, aided by a grant from the Royal Society. He at present holds a grant from the Nuffield Foundation to carry out a programme of research on neurosecretion in crustaceans. He is interested in the training of biologists and has been in charge of the biology department of Marlborough College since 1938. He has published a number of elementary textbooks of biology.



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# ENDEAVOUR

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# Joseph Black

Joseph Black had little interest in publication, preferring to communicate his knowledge by word of mouth, and it is perhaps not generally appreciated that his deservedly great reputation as an experimental chemist rests virtually on one published paper—'Experiments upon Magnesia Alba, Quicklime and some other Alcaline Substances'. But this one masterly paper, in which he quantitatively interprets the relationship between carbon dioxide (fixed air) and magnesia, lime, and other simple alkalis, has now stood the test of two centuries—for his final account of his experiments was read in June 1755. This paper may be justly said to mark the beginning of a new era of chemistry, in which the balance became the arbiter of experiment. The immensely fruitful results which stemmed from the introduction of quantitative methods need no emphasis now.

Black was born, one of a family of thirteen children, at Bordeaux in 1728. His father was an Irish merchant, and his mother, who undertook his early education, a Scotswoman. At the age of fourteen he was sent to Glasgow to study medicine at the university. There he came under the influence of Cullen, who was then professor of medicine and soon began, according to the custom of the time, to give lectures in chemistry, a subject not previously taught in Glasgow. Black was fortunate in attracting the favourable attention of Cullen, who not only made him assistant in his laboratory—a most valuable training in itself—but treated him as one of his own family.

Chemistry at that time was commonly looked upon as no more than a useful adjunct of pharmacy and had still not thrown off the mantle of medievalism. The teachings of Boyle had gone largely unheeded for two generations and the four Aristotelian elements were still generally accepted. Nevertheless, some unifying concepts had been developed. The phlogiston theory, which Black himself did not finally reject until 1791, deserves more respect than is sometimes accorded it; although it finally proved fundamentally wrong, it served for a long time as a stimulating working hypothesis and made possible some helpful classification of existing chemical knowledge. At the same time, the concepts of acids, bases, and salts were beginning to be formulated. The conversion of limestone into quicklime by strong heating was well known; in this process some innate virtue of the fire was supposed to be passed on to the lime. That mild alkalis could be made caustic by treatment with quicklime was ascribed to the passing on of this same fiery or caustic element. The true relationship between the various alkaline substances, which Black so brilliantly elucidated, was, however, still unknown.

Black's interest in this branch of chemistry was originally medical. Stone in the kidney was a well known but—in the then primitive state of surgery—very intractable condition, and attempts were made to dissolve and disperse the stones by treating them with caustic alkali. The dire effects likely to result from this kind of treatment need no description in the light of present knowledge, and it is not surprising that Cullen turned his thoughts to the possibility of using milder alkalis for the purpose; in consequence Black began a study of the properties of magnesia alba (magnesium carbonate). This substance had previously been studied by Friedrich Hoffmann, who distinguished between the oxides of calcium and magnesium. Black showed that the carbonates of the two metals differed in that on treatment with sulphuric acid one gave an insoluble product, whereas the other yielded a soluble substance which proved to be identical with Epsom salt.

Black's experiments on magnesia began in 1752, in which year he changed his place of study to Edinburgh. Two years later he presented for the degree of Doctor of Medicine a thesis entitled *De humore acido a cibis orto et magnesia alba* ('On the acid humour arising from food and on magnesia alba'). This thesis is a catalogue of thirty-two experiments, prefaced by some account of the nature of the digestive process. On his own admission, however, the latter was added principally to give the thesis the requisite medical flavour. When he read a revised version of the thesis in Edinburgh in the following year the study of digestion was omitted, but a second part, dealing at length with the constitution of chalk and lime, was added.

The differences between the versions of 1754 and 1755 are striking. Both reveal the essential facts, but a comparison reveals the man. It is a commonplace that study of the evolution of some work of art from sketch to sketch may lay bare the workings of the creative mind, but the history of science has hitherto been little studied from this point of view. Black's papers suggest that such study may be well rewarded. In 1754 Black expresses his



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ideas about fixed air cautiously and with reservations. He makes tentative suggestions and describes isolated results: clearly he is reluctant to commit himself. But by 1755 all his doubts are resolved and, with brilliant logic, he expresses his ideas definitely and incontrovertibly. This paper is now acknowledged as a classic, and the discoveries described are today an essential part of chemistry.

The most important experiment was that in which a known weight of magnesia alba was calcined, the product was dissolved in acid, and the original weight of material was recovered by addition of mild alkali (sodium or potassium carbonate). Black concluded that the loss of weight on calcining was due to the loss of an 'air' normally 'fixed' in the magnesia alba and consequently 'fixed' also in the mild alkali. Similar experiments, described in the paper of 1755, he interpreted as showing that the formation of lime from chalk was due to the liberation of 'fixed air' and that the causticization of mild alkalis was due to the transference of 'fixed air', and not some imponderable caustic or fiery virtue, from substance to substance.

Black's work had many consequences, but the most important was that it showed the need to put the whole of chemistry on a quantitative basis —the balance became an indispensable laboratory tool. Moreover, by weighing gases in combination, Black brought these elusive substances, too, within the scope of quantitative work, and so made the first steps which prompted the giant strides of Priestley, Cavendish, and Lavoisier.

But this was not all, as Lavoisier saw clearly. The weights of reactants and products meant no more than any other physical properties unless there were some underlying unity. Only if matter is conserved can the balance make sense, and it is the cyclic quality of Black's experiments which is so significant. When Lavoisier came to define the role of oxygen in combustion his work with mercury had the same cyclic character as Black's.

As has been said, Black's reputation as a chemist rests largely, so far as published work is concerned, upon a single paper. He made, however, one other notable contribution to science, again while still a comparatively young man, but this was in the field of physics. The nature of heat was still not understood—and nearly a century was to elapse before the notion of heat as an intangible fluid, or caloric, was abandoned—but Black's ideas were in advance of his time. He was the first to understand the nature of latent heat, and in doing so he devised valuable new methods of calorimetry. He was aware of the practical implications of these investigations, and he lent James Watt fifteen hundred pounds to assist him in the development of the steam engine. Black's work on latent heat led Watt to realize that unnecessary condensation in the cylinders of his early steam engines caused a serious lowering of efficiency. Watt overcame the difficulty by effecting the condensation in a separate vessel and maintaining the temperature of the cylinder by means of a steam-jacket. Black then gave him further assistance by introducing him to John Roebuck, the ironmaster, who materially helped the further development of the 'condensing' engine, though it was some years before other technical difficulties, notably the accurate boring of cylinders, were overcome.

Black's experimental work marked the opening of a new era, and entitles him to be looked upon as one of the founders of modern chemistry, but neither chemistry nor science as a whole advances only through great discoveries. The teaching of science—the handing on of new knowledge, its understanding simplified by the formulation of unifying theories and the removal of errors and unnecessary detail—is no less important. In this sphere alone Black would have made a great name for himself, for he was certainly in the same class as great formative teachers like Lémery and Rouelle. His clear instruction and unhesitating leadership put a whole generation of chemists—among them Thomas Beddoes, 'discoverer' of Humphry Davy—in his debt. Never slow to acknowledge the work of others, he was among the first to teach the new doctrine of Lavoisier. It is quite untrue that Black clung unduly long to the phlogiston theory because of personal antipathy to Lavoisier.

In a dissertation of 1787 John Carmichael epitomizes the qualities of Black and Lavoisier, referring to the former as '*clarissimus*' and the latter as '*hodie primarius scientissimus*'; with this relative assessment most historians of chemistry will agree.



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# Alchemy in medieval Islam

E. J. HOLMYARD

For the period with which this article deals, any attempt to differentiate between alchemy and chemistry would be vain; chemistry as a science is not yet three centuries old, and the practical operations out of which it grew were the operations of alchemy. In the early Middle Ages the chief exponents of alchemy were Arabic-writing Muslims of various races, and our words alchemy and chemistry, whatever their ultimate origin, are derived immediately from the Arabic *al-kīmīa*. Western alchemy is almost entirely a direct legacy from Islam.

It is not yet possible to write a definitive account of alchemy in medieval Islam, for thousands of Arabic manuscripts on the subject lie unexamined in the great libraries of Europe, Egypt, Turkey, India, and Pakistan. Not until they have been studied can a final estimate be made, and there are far too few scholars engaged on this task to make its early accomplishment feasible. In spite of Berthelot's pioneer efforts towards the end of last century, little was known with certainty of Muslim contributions to alchemical theory and practice until the last few decades, though tradition, on the principle *omne ignotum pro magnifico*, ascribed to the Arabs a virtuosity in the occult arts that 'The Thousand Nights and a Night' subsequently did much to reinforce. At the present time, owing mainly to the researches of H. E. Stapleton, Julius Ruska, M. Plessner, and Paul Kraus, we can form a picture of Muslim alchemy that seems likely to be correct in outline, even though still seriously lacking in detail.

The Islamic era or Hegira dates from A.D. 622, the year of the Prophet's flight (*hijra*) from Mecca. One hundred and ten years later, a Muslim army was defeated at Poitiers by Charles the Hammer. In the interval, Islam had become a vast empire stretching from the Indus to the Pyrenees, and many and various races had become incorporated into its civilization. Some of these peoples continued to speak their own languages, but Arabic was the religious, official, and literary language throughout the empire. Thus it happened that numerous Muslim works on alchemy are Arabic only linguistically, their authors being of Persian or other nationality. The contribution of the Arabs to knowledge was no greater than that made by their Muslim, Christian, and Jewish subjects.

## ORIGINS AND TRANSMISSION OF ALCHEMY

At the time of the rise of Islam, alchemy was already an art of venerable age. It was of a dual character. On the one hand it embraced specialized portions of metallurgy, dyeing, and similar crafts, and impinged at many points on medicine. On the other hand it was a semi-mystical cult of an eclectic kind, drawing its tenets whence it listed. The main aims of the alchemists were to prepare the philosophers' stone, which should convert base metals into gold, and further to prepare an elixir to prolong human life indefinitely.

The origin of alchemical theory is still far from clear, and possibly such speculation arose independently in more than one early civilization. In the west it certainly owed much to Aristotle's views on the nature of matter and to the Pythagorean theory of numbers [1], but the weight of evidence is that the fundamental ideas arose in the ancient Persian Empire, which included Mesopotamia, Asia Minor, Syria, and Egypt. Forbes [2] suggests that three streams of thought contributed to the rise of alchemy:

(*a*) The philosophy and technology of the ancient Near East.

(*b*) The philosophical tenets of the Persian and Indian civilizations.

(*c*) The philosophy and science of the Greeks.

The earliest alchemical treatises come from Hellenistic Egypt. Perhaps the most ancient of them is the *Physika kai Mystika*, 'Physical and Mystical Matters', of an author writing under the name of Demokritos; he probably lived in the second century A.D. and is not to be confused with the celebrated philosopher Demokritos of Abdera (d 376 B.C.). A large collection of alchemical writings was made by Zosimos of Panopolis (*c* A.D. 300), who also wrote original works on the subject, and many commentaries on earlier authors were compiled by succeeding Graeco-Egyptians such as Olympiodorus (*c* 500?). Further north, alchemy was practised by the Sabians of Harran (*Carrhae*) in Syria. Harran, long since



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destroyed, was a cosmopolitan city at which, during the Achaemenid period (*c* 650–530 B.C.), there began to take shape a remarkable intermixture of Persian, Syrian, and Greek natural philosophy. This syncretic system remained a characteristic of Harran for several centuries, and the city's reputation for catholicity of learning was still high in early Islamic days. Harran is also known to have possessed many able metallurgists, and to have traded extensively in the precious metals, sulphur, sulphides of arsenic, borax, and other substances commonly used in alchemy.

The Muslim conquerors soon manifested an enthusiasm for knowledge, and having overrun not only Alexandria and Harran but all the other principal centres of Greek learning they were able to indulge it to the full. Under rulers such as Hārūn al-Rashīd (764?–809) and Al-Ma'mūn (786–833) large numbers of academies and observatories were set up and the chief Greek works on philosophy, astronomy, mathematics, medicine, and other sciences were translated into Arabic, principally by Syriac-speaking Nestorian Christians. From the eighth century onwards Islam was producing scholars of her own.

According to Al-Nadīm, a tenth-century biographer, the first Muslim to interest himself in alchemy was Khālid ibn Yazīd (d 704), a son of the royal house but never himself Commander of the Faithful. Stapleton [3] renders the relevant passage as follows:

> Being himself a scholar, he [Khālid] was greatly interested in the sciences. He was particularly attracted to the Art [of *Kīmīa*]: so he ordered some Greek philosophers who lived in the city of Miṣr [Cairo], and who had a good knowledge of Arabic, to be summoned, and instructed them to translate the books on the Art from the Greek and Coptic languages into Arabic. This was the first translation from one language to another in Islam.

Some Arabic alchemical works ascribed to Khālid are still in existence but have not yet been closely studied; most of them, like those of many later alchemists, are in verse.

### JĀBIR IBN ḤAYYĀN

The greatest name in alchemy, whether Muslim or Christian, is that of Jābir or Geber: alchemists themselves were described by one of their number, Thomas Norton of Bristol (fifteenth century), as 'Geber's cooks'. The life and works of this master of the art have presented a very difficult historical problem, which, however, research carried out during the last fifteen years has gone far to solve. There seems no reason to doubt that at the court of Hārūn al-Rashīd there was an alchemist named Jābir ibn Ḥayyān al-Ṣūfī, the son of a druggist of Kufa. As a young man he enjoyed the patronage of the sixth Shī'ite Imam, Ja'far al-Ṣādiq, and later that of the caliph's powerful ministers the Barmecides. He was probably born in 721 or 722, but the date of his death is unknown; he is said to have survived the banishment of the Barmecides in 803. Muslim chroniclers describe him as a man of culture and scholarship, and say that he was active in securing the importation of further Greek works on science and philosophy from Byzantium.

Difficulties begin to arise when consideration is given to the very numerous treatises on alchemy that pass under his name. There are so many of them that it seemed hardly possible for one man to have written them all, and the suspicion grew that some at least were fathered on him by later writers. The brilliant investigations of Kraus [4] showed that the suspicion was well founded. Critical examination of the Jābirian Arabic *corpus* proved beyond doubt that much of it must have been recensed or perhaps originally written by members of the Ismā'ilite sect early in the tenth century. How much of the alchemical operations and theory described in it is of the eighth century and how much of the tenth must remain a matter of conjecture: here, for economy of words, it will be referred to merely as 'Jābir'.

On the constitution of matter, Jābir held the Aristotelian conception of the four elements, fire, air, water, and earth, but developed it on different lines. He postulated first the existence of four elementary qualities or 'natures', namely hotness, coldness, dryness, and moistness. When these natures united with substance they formed compounds of the first degree, namely hot, cold, dry, moist. Union of two of these gave rise to fire (hot + dry + substance); air (hot + moist + substance); water (cold + moist + substance); and earth (cold + dry + substance). In metals, two of the 'natures' are external and two internal, a point to which further reference is made later (p. 122). Thus in his 'Book of Seventy' Jābir says that lead is cold and dry externally and hot and moist internally, as is also silver (but see p. 122); gold, on the other hand, is hot and moist externally and cold and dry internally.

He believed that, under the influence of the planets, metals were formed in the earth by the



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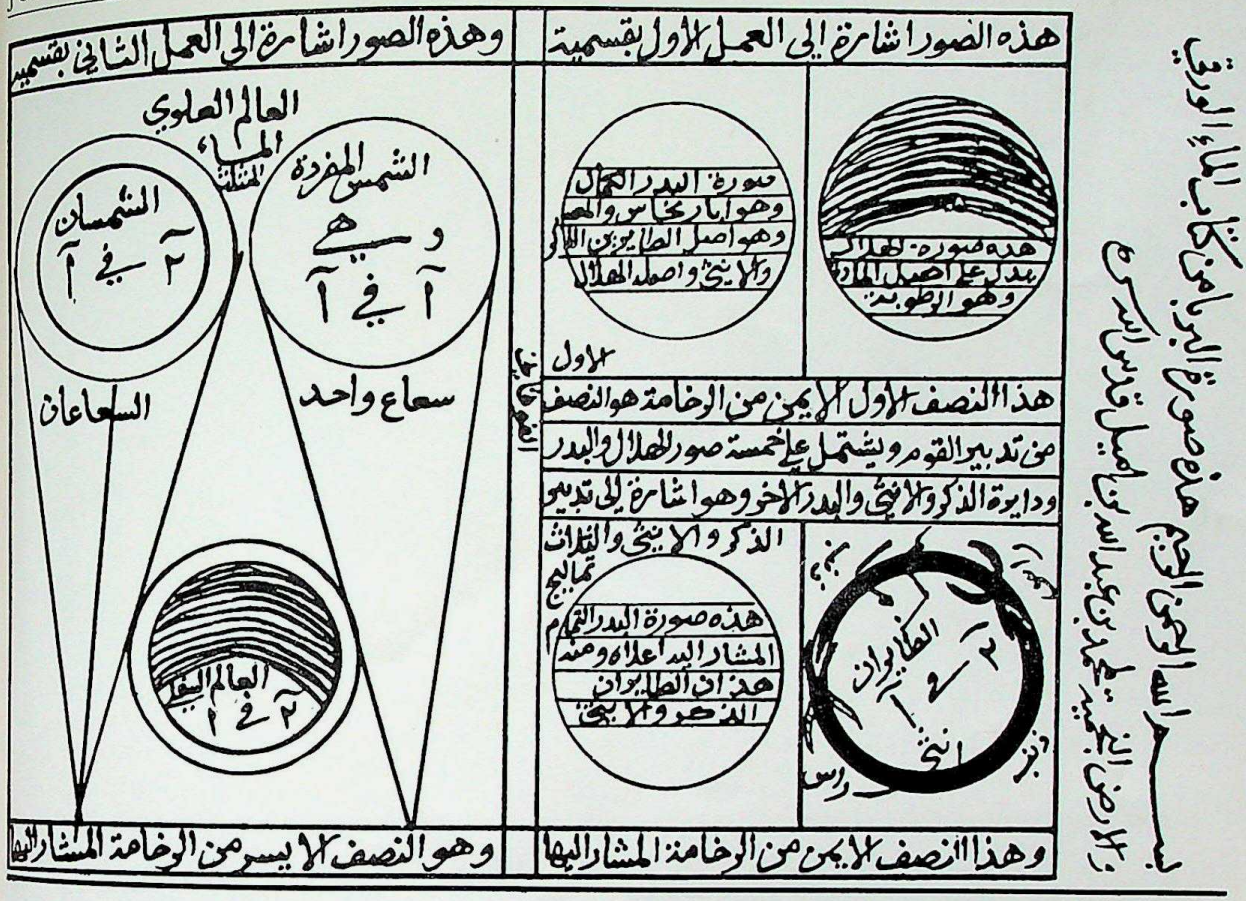


And these pictures indicate the 'Second Operation' in its two parts.

These pictures indicate the 'First Operation' in its two parts.

The Higher World
The Triple Water

(i) The Two Suns, Two in One

The Single Sun, and it is One in One

The Two Rays

Single Ray

The Lower World, Two in One

The picture of the Full Moon, and it is the *Abār-Nuḥās* and *Magh(nīsiyā)*, and it is the origin of the two birds, male and female, and its origin is the New Moon.

This is the picture of the New Moon, indicating the origin of matter (*Aṣl al-Māddah*), which is moisture.

This is the first (and the) right half of the tablet. It is the first half of the 'Operation of the People' and includes five pictures—the New Moon, the Full Moon at its zenith, the Circle of the Male, the Circle of the Female, and another Full Moon. And this indicates the 'Operation of the Male and the Female' and the 'Three Saltings.'

This is the picture of the Perfect Full Moon, referred to above, and from this come these Two Birds, the male and the female.

Tail Male Head
The Two Birds Two in One
Head Female Tail

Bismillāh. This the Pyramid (*Birbā*) Picture from the book called *Al-Mā' al-Waraqī wa'l Ard an-Najmīyah* ('Silvery Water and Starry Earth') by Muhammad bin 'Abdullāh bin Umail. May Allāh sanctify his heart!

And this is the left half of the marble tablet referred to above.

And this is the right half of the marble tablet referred to above.

FIGURE 1 – *Facsimile of a page of an Indian MS of the Mā' al-Waraqī containing symbolical pictures (with translation of texts given below).* (*From* Mem. Asiat. Soc. Beng., 12, No. 1, *Plate* 1, 1933.) (*By courtesy of Dr H. E. Stapleton.*)



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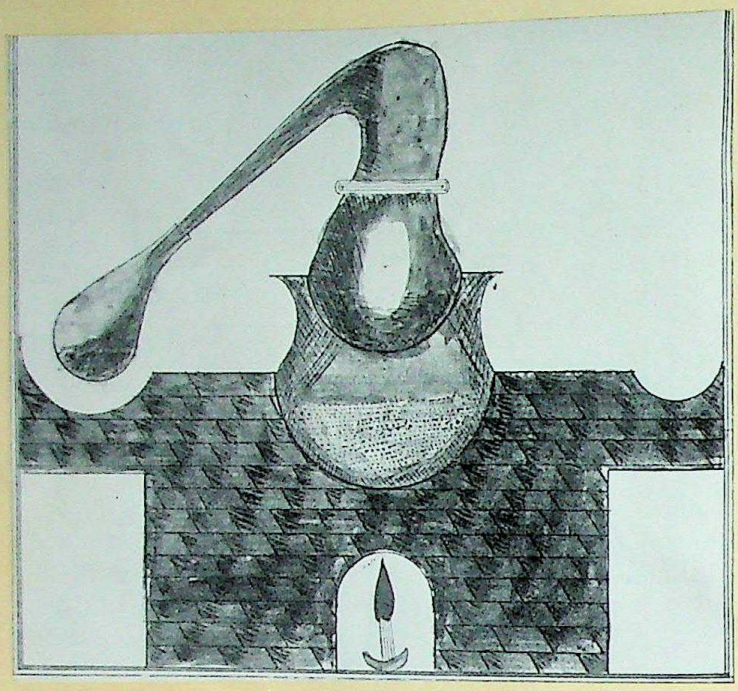

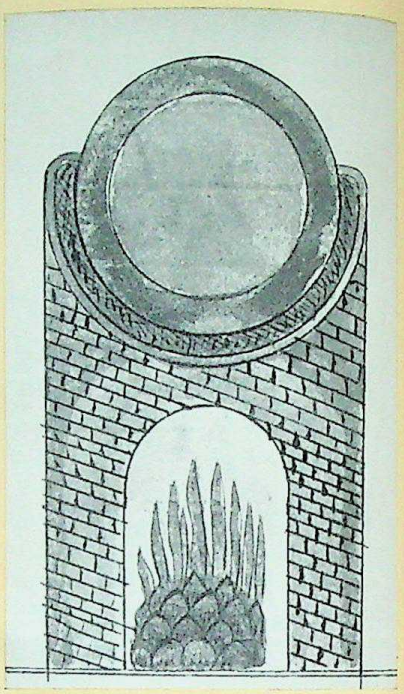

FIGURES 2 and 3 – *Stills, from an Arabic alchemical manuscript* (British Museum Add. 25724).

FIGURE 4 – *From an Arabic alchemical manuscript. The inscription reads: Know that the compound referred to has specific weights that should be in equilibrium, so that the hotness does not overcome the coldness or the dryness overcome the moistness. For what is in equilibrium will possess permanent natures and will never undergo change, while natures not in equilibrium will suffer alteration.* [*Sun to the left, Moon to the right. Figures between possibly represent iron, copper, lead, tin, mercury, and Khār sīnī.*] (British Museum Add. 25724.)

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union of sulphur (which would provide the hot and dry 'natures') and mercury (providing the cold and moist). This theory, which appears to have been unknown to the ancients, may have been original, though it is possible that Jābir appropriated it from Balāniūs (Apollonius of Tyana). The reason for the existence of different kinds of metal is that the sulphur and mercury are not always pure, and that they do not always unite in the same proportion. If they are perfectly pure, and if also they combine in the most complete natural equilibrium, then the product is the most perfect of metals, namely gold. Defects in purity, and particularly in proportion, result in the formation of silver, lead, tin, iron, or copper, but since these metals are essentially composed of the same constituents as gold, the accidents of combination may be rectified by suitable treatment. Such treatment is the object of alchemy, and is to be carried out by means of elixirs.

Jābir was convinced that to try to effect transmutations empirically was a waste of time; he believed that order reigned in the material world, and that qualitative changes in substances could be explained on a quantitative basis. He was thus led to his characteristic conception of 'balance' (*mīzān*), which he elaborated particularly in his 'Books of the Balance' (*Kutub al-Mawāzīn*). By balance he did not refer to equality of weight; in fact, although he does describe a hydrostatic balance, the importance of comparing masses was as little perceived by him as by all other alchemists. His balance was an equilibrium of elementary qualities or 'natures', and a great deal of his work was devoted to attempts to establish the equilibrium figures in gold—the perfect metal—so that the same balance could be effected in base metals, thus bringing about their transmutation.

Except for the history of ideas, it would be unprofitable to follow the development of such a scheme in detail, but it is of interest to examine one of the lines of attack. This has been done by Kraus [5] and Stapleton [6], on whose work the following account is principally based. We find throughout Jābir's works a series of numbers to which he attaches great importance: it is 1, 3, 5, 8 (totalling 17), and 28. He says that everything in the world is governed by the number 17—metals, for instance, have 17 'powers'. Now the numbers composing the total of 17, namely 1, 3, 5, 8, recall the magic square of the first nine digits:

| | | |
|---|---|---|
| 4 | 9 | 2 |
| 3 | 5 | 7 |
| 8 | 1 | 6 |

Here the total is 45, but analysing the square gnomonically, as indicated by the heavy lines in the figure, gives 1, 3, 5, 8 in the remaining square, while the total in the gnomon is 28. This magic square, which was known to the Neoplatonists of the third century and is doubtless much older, is thus clearly the source of Jābir's significant numbers. He does not appear to have specifically mentioned it, but it must have been familiar to him not only from his acquaintance with Neoplatonist writings but because it had significance in the Ṣūfī mystical society of which he was a member.

One way in which Jābir used these numbers was in the application of alphabetical numerology to elucidate the constitution of the metals. Each of the four elementary qualities or 'natures' was supposed to have four degrees and seven subdivisions, giving a total of 28 × 4 'positions'. The letters of the Arabic alphabet, 28 in all, were assigned to the subdivisions of heat, coldness, dryness, and humidity, and the scheme was extended to the values of the four degrees according to the series 1, 3, 5, 8. The degrees and subdivisions were equated to weights on the Arabic system of 2 *qīrāṭs* = 1 *dānaq*, 6 *dānaqs* = 1 *dirham*, and a table was constructed in which, for example, the letter *b* denoted, in the second degree of coldness, a weight of $3\frac{1}{2}$ *dirhams*; in the fourth degree *b* corresponded to a weight of $9\frac{1}{3}$ *dirhams*. The remaining letters were similarly 'calibrated'.

To determine the 'balance' of lead on this scheme, its name was analysed arithmo-alphabetically, only the consonants being used. Lead in Arabic is *usrub*, but the first letter, not indicated in the transliteration, is the consonant *alif*. *U* being a vowel, the operative letters are therefore *alif*, *s* (*sīn*), *r* (*rā*), and *b* (*bā*). *Alif*, being the first letter of the name, represents heat of the first degree, and is equivalent to a weight of 7 *dānaqs*; *sīn*, the second letter, represents dryness of the second degree, and is equivalent to 1 *dirham*; *rā* represents humidity of the third degree, $1\frac{1}{4}$ *dirhams*; and *bā* represents coldness of the fourth degree, that is $9\frac{1}{3}$ *dirhams*. Hence a lump of lead weighing $12\frac{3}{4}$ *dirhams* would contain the above weights of heat, dryness, humidity, and coldness, and this



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composition would hold for any specimen of lead. The fact that another name for lead, namely *raṣāṣ*, gives an entirely different result may cause misgivings as to the reliability of this method of analysis.

It was mentioned earlier that Jābir distinguished between the external and the internal composition of a metal. One reason for this distinction can be found in the figures just elicited. Metals are composed of heat, cold, dryness, and humidity, but there is a limiting condition: opposing 'natures' are in the ratio of either 1 : 3 or 5 : 8 or *vice versa*. The figures for lead, however, do not agree with these ratios, and the difficulty is even greater when *fiḍḍa* (silver) is analysed in the same way—it proves to consist merely of heat and coldness in equal proportions. Jābir was therefore forced to use a further hypothesis, namely that the analysis reveals only the peripheral constitution; the balance must be restored by the constitution of the interior. Hence for silver the total composition, external and internal together, must be arrived at by calculation:

Heat:

$1\frac{1}{2}$ *dānaqs* + a complement of $5\frac{1}{2}$ *dānaqs* = $1\frac{1}{8}$ *dirhams*

Coldness:

$1\frac{1}{2}$ *dānaqs* + a complement of $3\frac{1}{4}$ *dirhams* = $3\frac{1}{2}$ *dirhams* $(= 3 \times 1\frac{1}{8})$

Humidity:

0 *dānaqs* + a complement of $5\frac{5}{8}$ *dirhams* = $5\frac{5}{8}$ *dirhams* $(= 5 \times 1\frac{1}{8})$

Dryness:

0 *dānaqs* + a complement of $9\frac{1}{8}$ *dirhams* = $9\frac{1}{8}$ *dirhams* $(= 8 \times 1\frac{1}{8})$

$19\frac{5}{8}$ *dirhams* $(= 17 \times 1\frac{1}{8})$

The unit of $1\frac{1}{8}$ seems to be chosen here so that fractions of a *dirham* not represented by either a *dānaq* or a *qīrāṭ* are avoided.

The transmutation of one metal into another is thus an adjustment of the ratio of the manifest and latent constitutions of the first to those of the second, an adjustment to be brought about by an elixir. According to Jābir there are various elixirs suitable for specific transmutations, but transmutations of every kind can be brought about by a grand or master elixir (*al-iksīr al-a'ẓam*). The Alexandrian and Harranian alchemists appear to have used only mineral substances in their attempts to prepare elixirs for transmutation, but Jābir was an innovator and introduced both animal and vegetable products to the alchemical armoury. Among the former he mentions the marrow, blood, hair, bones, and urine of lions, vipers, foxes, oxen, gazelles, and donkeys both domesticated and wild. Suitable plants included aconite, olive, jasmine, love-in-a-mist, onion, ginger, pepper, mustard, pear, and anemone.

Such lists provide an indication that Jābir was more than a theorizer, and there is indeed much in his books to show that he was well versed in chemical operations. Though his theory is complex, obscure, and often to our modern minds ridiculous, he can be perfectly clear when giving instructions for a preparation. A single example must suffice:

> To convert mercury into a red solid. Take a round glass vessel and pour a convenient quantity of mercury into it. Then take a Syrian earthenware vessel [Syrian pottery enjoyed a high reputation in those days] and in it put a little powdered sulphur. Place the glass vessel on the sulphur and pack it round with more sulphur up to the brim. Place the apparatus in the furnace for a night, over a gentle fire . . . after having closed the mouth of the earthenware pot. Now take it out and you will find that the mercury has been converted into a hard red stone the colour of blood . . . it is the substance that the learned call cinnabar.

Of alchemical equipment, both substances and apparatus, Jābir gives a less systematic description than Rāzī (p. 123), but he does classify minerals into three groups. These are (*a*) spirits, or substances that volatilize completely on heating; (*b*) metals, or fusible substances that are malleable, sonorous, and possess a lustre; and (*c*) substances that, whether fusible or not, are not malleable and may be powdered. The spirits numbered five: sulphur, arsenic [sulphides], mercury, camphor, and sal ammoniac. This is one of the earliest Arabic mentions of sal ammoniac (*nūshādur*), which for a time was imported from inner Asia; it was probably obtained there as a sublimate from burning coal-seams [7]. Jābir, however, knew how to prepare it from organic matter, and distinguishes between the mineral form and the sal ammoniac 'from hair'.

There were seven metals, namely gold, silver, lead, tin, copper, iron, and *khār ṣīnī*. The last of these has not been identified with certainty; the name signifies 'Chinese iron', and Muslim writers say that it was used in China to make mirrors with the power of curing ophthalmic maladies of sufferers looking into them. It was also cast into bells of a particularly melodious tone. According to Laufer [8], it was an alloy chiefly composed of



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copper, zinc, and nickel; it gave a silvery surface when polished and was known as *pai-t'ung* or white copper. There could have been very little of it available in Islam, and for the most part it was included among the metals only to bring their number up to seven when mercury was classed as a spirit.

Jābir's classification of minerals other than spirits and metals was not consistent, but in one book he sorts them into eight groups, according to whether they are (*a*) stony or not stony, (*b*) pulverizable or not pulverizable, and (*c*) fusible or non-fusible. Though such a system cannot be pressed very far, it is at least on sensible lines.

It is a matter of considerable interest that the Arabic text of the celebrated *Tabula Smaragdina*, or Emerald Table, of 'Hermes' was first discovered in Jābir's 'Second Book of the Element [στοιχεῖον] of the Foundation' [9]; before this discovery (1923) it had been known only in medieval Latin. Jābir says that he is quoting Apollonius of Tyana, and another version of the *Tabula* has been found in a book called 'The Secret of Creation' (*Sirr al-Khalīqa*) probably dating from the early ninth century and ascribed to Apollonius. The original language of the *Tabula* is unknown, but there are indications that it may have been Syriac. In its Latin form it is perhaps the best known piece of alchemical literature.

Some final remarks on Jābir must concern the problem of the authorship of the Latin works, such as the *Summa perfectionis*, ascribed to him. These appear first about the end of the thirteenth century, and of only one of them (the 'Book of Seventy'—not included in any of the collected Latin editions) is an Arabic original known. The others admittedly show signs of Muslim influence, but that is true of most early western alchemical works and is only to be expected in view of the fact that alchemy in Latin Europe was almost entirely an importation from Islam. The weight of evidence is in favour of the judgment that, because of the authority of his name, works written by an anonymous European alchemist were circulated as Jābir's.

### RĀZĪ

Later than Jābir ibn Ḥayyān, though possibly contemporaneous with the writing of some of the Jābirian *corpus*, was Abū Bakr Muḥammad ibn Zakariyya, known as Al-Rāzī, 'the man of Ray' (*Rhagae*), from his birthplace near Teheran. He lived from 866 to 925. Rāzī was the greatest physician of the Middle Ages, and his works on medicine enjoyed an unquestioned authority extending over some six hundred years. He made many contributions to gynaecology and ophthalmology, and the monograph in which for the first time he distinguished between smallpox and measles is one of the classics of medicine. He practised at his native town and also at the great hospital in Baghdad, and his success as a clinician was matched by his outstanding ability as a teacher of medicine.

Like many physicians of medieval times, he was attracted to the study of alchemy and is said to have written a score of books on the subject; they have not all survived, but one of them, 'The Book of the Secret of Secrets' (*Kitāb Sirr al-Asrār*), has been translated into German and furnished with a commentary by Ruska [10]. Much of his alchemical work has also been studied by Stapleton, who places him on an intellectual level with Galileo and Boyle.

The metaphysical background of Rāzī's alchemy resembles that of the Jābirian writings: it is Ismā'ilite and therefore tends towards the spirit of free inquiry. The object of alchemy is still the transmutation of base metals into gold by means of elixirs, but a study of the *Kitāb Sirr al-Asrār* and other books of Rāzī conveys the impression that he was much more interested in practical chemistry than in theoretical alchemy. The *Kitāb Sirr al-Asrār* foreshadows a laboratory manual, and though the procedures described are often difficult to interpret they are probably representative of experiments that Rāzī himself had carried out. From the list he gives of materials and apparatus it is evident that his laboratory was very well equipped. It had beakers, flasks, phials, basins, glass crystallizing-dishes, jugs, casseroles, candle-lamps, naphtha-lamps, braziers, athanors, smelting-furnaces, files, spatulas, hammers, ladles, shears, tongs, sand- and water-baths, filters of hair-cloth and linen, alembics, aludels, funnels, and mortars. In addition, Rāzī gives details of the construction of more complicated pieces of apparatus from these and other units.

His store-cupboard contained not only specimens of all metals then known, but pyrites, malachite, lapis lazuli, gypsum, haematite, turquoise, galena, stibnite, alum, green vitriol, natron, borax, common salt, lime, potash, cinnabar, white lead, red lead, litharge, ferric oxide, cupric oxide, verdigris, and vinegar. Stapleton has adduced reasons for believing that Rāzī was also familiar with caustic soda and glycerol. It is uncertain whether he was acquainted with sulphuric and nitric acids,



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but nitric acid was known to Jābir, who describes its preparation, and it was early used for the parting of gold and silver.

### AVICENNA

Abū 'Alī ibn Sīnā, known to the west as Avicenna, was born in 980 and died in 1036–7. Like Rāzī, he was a Persian of extraordinary intellectual capacity and a prolific writer, and his books had wide popularity both in Islam and in medieval Europe. It has been well said of him that his thought represents the climax of medieval philosophy. His most important works were the 'Canon of Medicine' and the philosophical encyclopaedia *Kitāb al-Shifā'*, or *Sanatio*.

In the mineralogical section of the *Shifā'*, which in medieval times and in Latin translation circulated under the title *Liber de mineralibus* and was ascribed to Aristotle [11], Avicenna accepts the sulphur-mercury theory of metals but expresses emphatic disagreement with the claims of the alchemists. There is little doubt, he says, that alchemists can contrive to make solids closely resembling gold and silver, but these products are mere imitations. 'I do not deny', he proceeds, 'that such a degree of accuracy in imitation may be reached as to deceive even the shrewdest, but the possibility of transmutation has never been clear to me. On the contrary, I regard it as impossible, since there is no way of splitting up one metallic combination into another. Those properties that are perceived by the senses are probably not the differences that distinguish one metallic species from another, but rather accidents or consequences, the essential specific differences being unknown.' In other words, while accepting that metals were of a compound nature, Avicenna thought their structure too stable to be affected by fusion and other alchemical methods. 'It is likely', he writes, 'that the proportion of the elements that enter into the composition of each of the metals is different from that of any other. If this is so, one metal cannot be converted into another unless its structure is broken up and converted into the composition of that into which its transformation is desired. This, however, cannot be effected by fusion, which maintains the union and merely causes the introduction of some foreign substance or virtue.'

Avicenna's views received little support; they were in advance of their time, and the alchemists pursued their search for elixirs undisturbed by doubts and with undiminished enthusiasm.

### LATER WRITERS

A younger contemporary of Avicenna was Ibn Umail, one of whose alchemical books, 'The Silvery Water' (*Al-Mā' al-Waraqī*), was translated into Latin in the Middle Ages and is printed in Zetzner's *Theatrum Chemicum* (1622). This work, the Arabic text of which was edited by Turab Ali [12] in 1933, is important as containing numerous quotations from earlier alchemical treatises otherwise unknown. Ibn Umail was of the opinion that the pyramids of Egypt were designed for the practice of alchemy, thus agreeing with the historian Al-Nadīm (*c* 988), who says: 'A pyramid contains rooms of different shapes in which are places for admixture, pounding, solution, coagulation, and distillation, which indicates that each of them was built for the art of *Kīmīa*.' Symbolic 'pyramid' figures from a manuscript of the *Mā' al-Waraqī* are reproduced in figure 1.

An early tenth-century work, ascribed—though with doubtful justification—to the Spanish Arab Maslama of Madrid, is called 'The Sage's Step' [13]. It contains the usual preponderance of theory, but there is also much straightforward information on various practical operations, particularly the refinement of gold and silver by cupellation and other methods. The author appears to have had more regard to quantitative observation than was usual, and in one experiment took a quarter of a pound of mercury, heated it moderately for forty days, and then weighed the resulting red powder; he could find no change in weight, but the fact that he made the determination is indicative of a careful and inquiring mind.

During the twelfth and thirteenth centuries the transmission of alchemical theory and practice from Islam to the west was accompanied by a decline in the number of Arabic writers on the subject: though perhaps future research will show that the decline was not as great as our present knowledge leads us to assume. Such books as were written were generally rearrangements of earlier ones or commentaries on them. Thus Abu'l-Qāsim al-'Irāqī, who lived in the thirteenth century, appropriated passages from the *Mā' al-Waraqī* and other books, with or without acknowledgment, and in doing so was merely following a common practice. There is, however, something to be said in favour of these purveyors of second-hand wares, for they often enable us to fill gaps in our knowledge of the earlier literature. One of them in particular, Aidamur al-Jildakī [14], is a most valuable source of information; with



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him, this sketch of Muslim alchemy may fittingly end.

Little is known of Jildakī's life. He flourished in the first half of the fourteenth century, lived for a time in Cairo, and spent seventeen years in extensive travel to meet the principal alchemists of the time and to collect alchemical writings. Most of the remainder of his life he must have devoted to authorship, for he wrote at least twenty-five books, some of them very lengthy. Their value lies in the very numerous quotations that Jildakī fortunately saw fit to include in them, a value enhanced by the general accuracy with which the quotations are made. In many cases the original works are still in existence, and examination of them shows that Jildakī was a careful copyist; we may therefore with fair confidence accept as genuine other passages of which no earlier provenance is known.

The great bulk of Jildakī's work still awaits detailed study, but a full examination has recently been made by Taslimi [15] of the *Nihāyat al-Ṭalab* or 'End of the Search', which is a commentary by Jildakī on Abu'l-Qāsim al-'Irāqī's book known as the *Muktasab* [16]. The richness of the material offered by Jildakī may be judged from the fact that in the *Nihāyat* alone he quotes from, or mentions, no fewer than 42 works of Jābir and a large number of works by other authors, including Ibn Umail, Avicenna (whom he accuses of plagiarizing Al-Fārābī), Maslama, Khālid ibn Yazīd, and Rāzī. Another of Jildakī's books that would well repay study is the *Kitab al-Burhān* or 'Book of Proof', which contains a commentary on 'The Book of the Seven Idols' ascribed to Apollonius of Tyana. Taslimi says that there is a great deal of similarity between the ideas contained in the quotations from Jābir given in the *Nihāyat* and those found in the Latin works of Geber; he does not, however, think the correspondence sufficient to establish a close connection.

The author wishes to express his thanks to Dr Manuchehr Taslimi for the gift of a copy of the thesis mentioned in reference 15.

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# Porphyrins

C. RIMINGTON

The porphyrins are among the most important of the natural pigments, but although they have been known for almost a century it is only within the last decade that the principal steps in their biosynthesis have been identified. This development is due in large measure to the introduction of isotopic labelling techniques. This research brings us towards an understanding of the biochemical lesions responsible for the various porphyria diseases.

Porphyrins are nitrogen-containing pigments which are very widely distributed in the animal and vegetable kingdoms. They occur either in the free state or in the form of complexes with metals, the iron complexes or haems being particularly important in animals, with which this article is primarily concerned. Much of our knowledge of the chemistry of the porphyrins we owe to Hans Fischer and his school at Munich, who from 1915 to 1945 carried out monumental researches upon their structure and chemistry. The first preparation of a porphyrin in a reasonable state of purity, however, was made much earlier; J. L. W. Thudichum, in a report to the British Privy Council in 1867 [1], described the action of strong acid upon blood and the separation from the mixture of a pigment which he called 'cruentine.' Some years later F. Hoppe-Seyler [2] renamed this substance 'haematoporphyrin', to indicate its red colour in solution and its origin from blood. This porphyrin is still known as haematoporphyrin and its chemical structure and relationship to haemoglobin are now clearly understood. Another most important pigment, still containing combined iron, was found to be readily prepared in crystalline form from haemoglobin by treating blood with hot acetic acid. Investigation of this substance, 'haemin', chiefly by Nencki, Küster, Willstätter, and finally by Fischer, revealed the true structure of the porphyrins.

The porphyrin molecule consists essentially of four pyrrole rings united by means of carbon bridges into a macrocyclic structure (figure 1). The simplest member would be that in which all the positions numbered 1 to 8 on the pyrrole nuclei were occupied by hydrogen atoms. This substance does not occur in nature, but can be prepared synthetically; to it Fischer gave the name 'porphin,' and on it he based a rational system of nomenclature for all the porphyrins. Thus, haematoporphyrin is known to have the structure shown in figure 2, and is accordingly described as 1, 3, 5, 8-tetramethyl-2, 4-di(α-oxyethyl)-porphin-6,

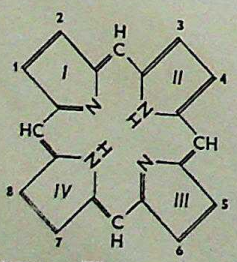


FIGURE 1 – *The porphyrin skeleton.*

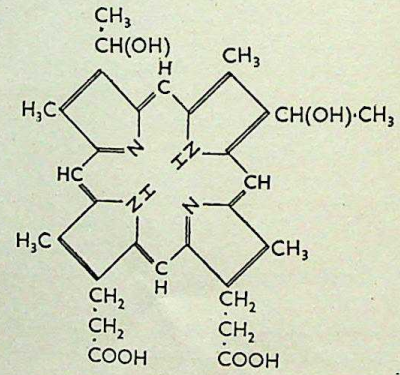


FIGURE 2 – *Haematoporphyrin.*

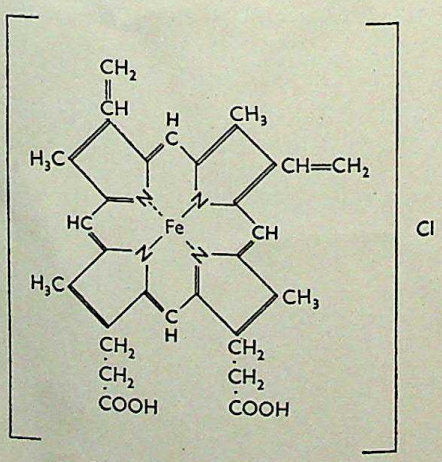


FIGURE 3 – *Haemin.*



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7-dipropionic acid. Haemin (figure 3) is the chloride of an iron complex; the only difference from haematoporphyrin in the porphyrin structure is that positions 2 and 4 carry vinyl groups in place of hydroxyethyl groups. Removal of the co-ordinately bound iron from haemin leads to protoporphyrin (figure 4).

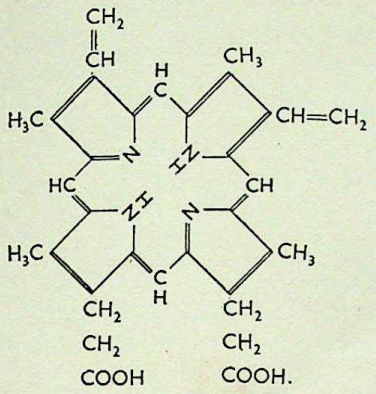


FIGURE 4 – *Protoporphyrin IX.*

It is clear that in a case such as that of protoporphyrin the formula depicted represents only one of the fifteen possible ways of arranging four methyl, two vinyl, and two propionic acid groups as substituents of the eight hydrogen atoms of porphin. The correctness of the structure reproduced, the ninth possibility, rests upon Fischer's synthetic work. Natural protoporphyrin is thus generally termed 'protoporphyrin IX.'

Fischer also prepared synthetically all four possible isomers of aetioporphyrin, in which four methyl groups and four ethyl groups are present as substituents on the pyrrole rings (figure 5). Each aetioporphyrin can be regarded as the theoretical starting point of a series of porphyrins derived by inserting vinyl, acetic acid, propionic acid groups, etc., in place of the ethyl groups. Figure 6 illustrates the four coproporphyrins, the roman numeral indicating from which of the four aetioporphyrin isomers the pigment is theoretically derived. Protoporphyrin IX is seen to be a series III porphyrin (figure 4). Were derivatives of all four isomeric types produced by living organisms, the variety of natural porphyrins would be very great, but pigments of series II and IV do not appear to be formed by living cells; this limits the natural coproporphyrins (figure 6) and uroporphyrins (figure 7) to two in each case. Protoporphyrin IX seems to be the sole protoporphyrin to occur naturally.

It has already been stated that the porphyrins are widely distributed in nature. Their detection is rendered easy by the fact that in addition to colour, the highly resonating porphyrin ring structure confers upon them two other properties, namely the exhibition of well-defined and characteristic absorption bands in the visual and near ultra-violet regions of the spectrum, and of an intense red fluorescence in ultra-violet light which permits the detection of as little as one part of porphyrin in a thousand million parts of a suitable solvent. Normal urine contains some 10–200 micrograms per litre of a mixture of coproporphyrins I and III and a smaller quantity of uroporphyrin. About a quarter of a milligram of coproporphyrins and some protoporphyrin is eliminated daily in the faeces. Both coproporphyrin and protoporphyrin are present in the red blood cells, where the main pigment is of course haemoglobin, composed of the protein globin united with 'haem,' the iron complex of protoporphyrin IX. Iron porphyrin complexes combined with other specialized proteins constitute the cytochromes, the respiratory catalysts, which are present in every living cell which utilizes oxygen; catalase, an enzyme which rapidly destroys hydrogen peroxide; and similar catalysts vital to the life of the cell. Chlorophylls *a* and *b* are magnesium complexes of modified porphyrin structures.

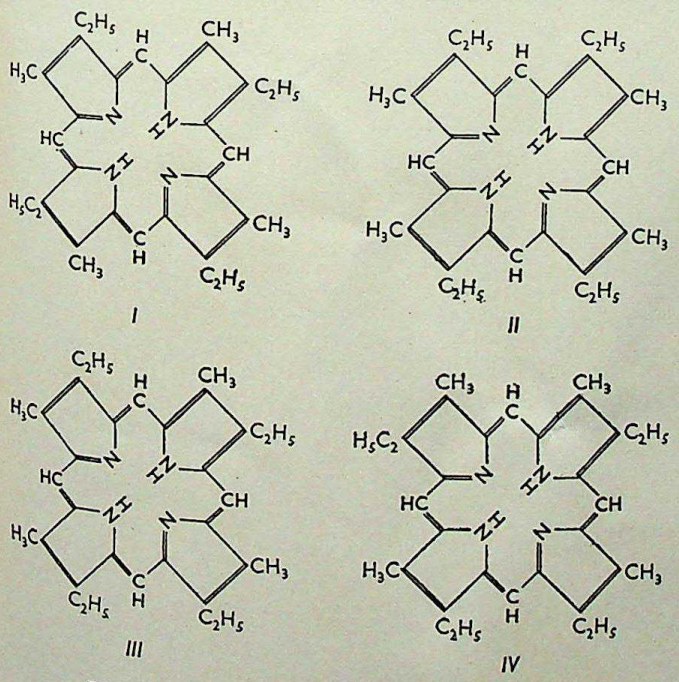


FIGURE 5 – *The four isomeric aetioporphyrins.*



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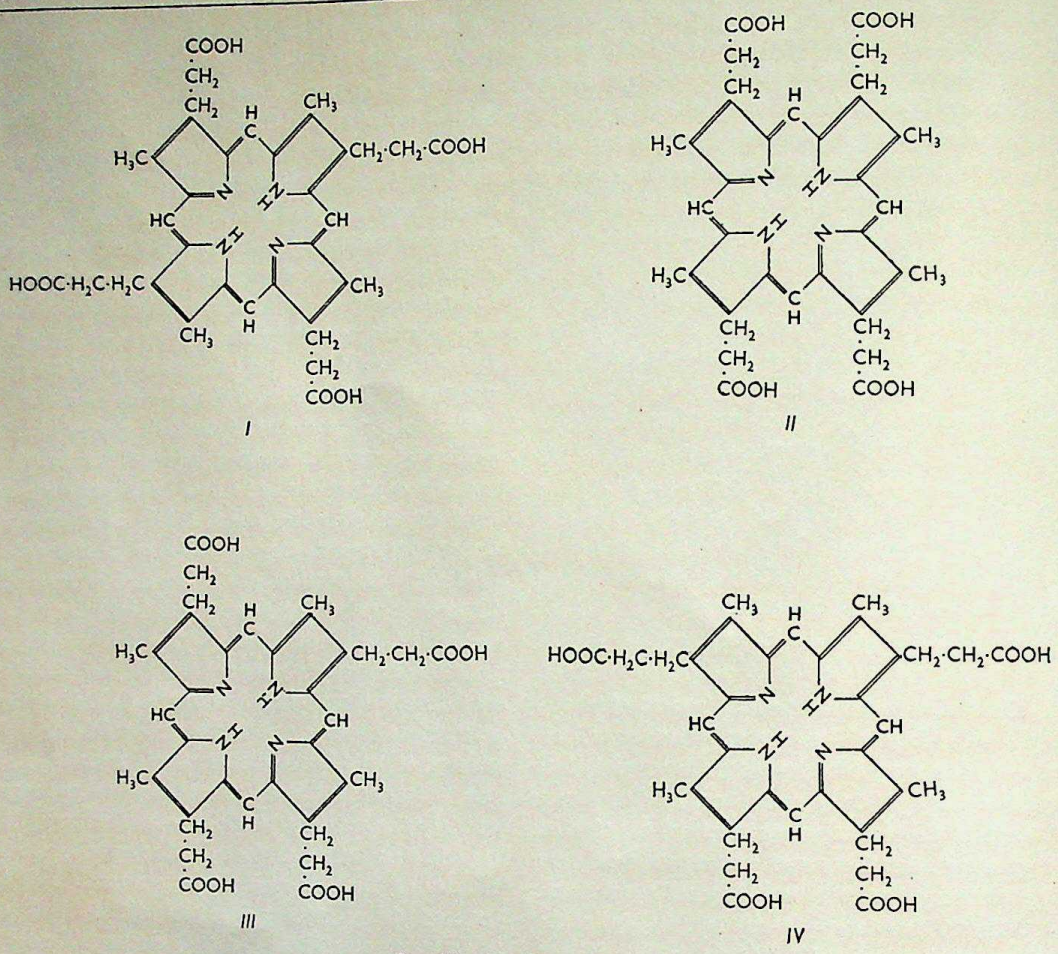


FIGURE 6 – *The four isomeric coproporphyrins.*

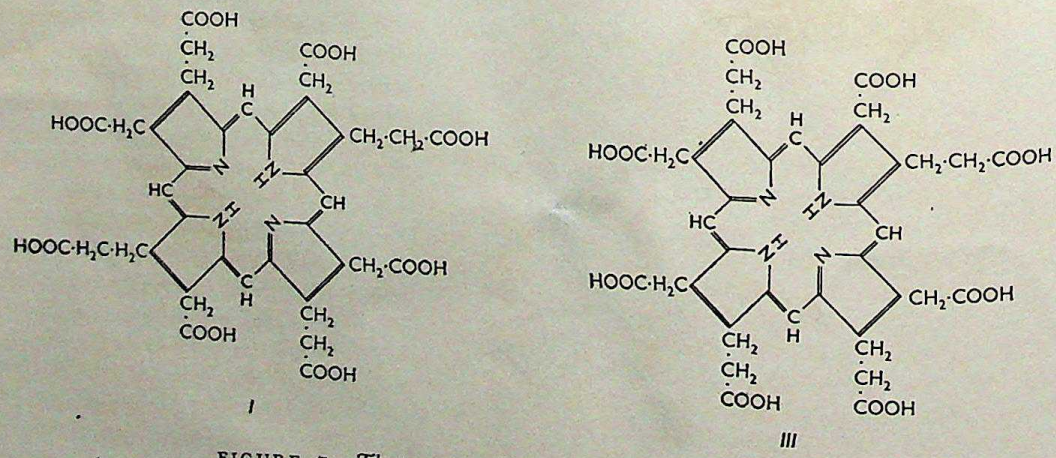


FIGURE 7 – *The two naturally occurring isomeric uroporphyrins.*



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Free porphyrins, that is to say porphyrins not bound to metals, can be detected in small quantities in most animal tissues and organs, including parts of the nervous system, but in some species peculiar localizations occur. Thus in rodents, such as the rat, the gland of Harder, which is associated with the lachrymatory apparatus, contains large quantities of protoporphyrin; its appearance when viewed by filtered ultra-violet light is very striking (figure 9). Whereas the bony skeleton of most animals contains too little porphyrin to be directly visible, that of the ground squirrel (*Sciurus niger*) and of some other rodents has a distinctly brownish tint and under ultra-violet light exhibits a brilliant red fluorescence (figure 14), that of the teeth being particularly striking. Such an association of porphyrin with calcified tissue is met with frequently; other examples are the deposition of uroporphyrins in certain marine shells and in the zones of calcification of foetal bones. A unique occurrence of a porphyrin derivative in nature is that of the copper complex of uroporphyrin III in the flight feathers of the turacos (*Musophagidae*), African birds allied to the cuckoo, where it imparts a brilliant and very beautiful red colour to the wings.

We owe much of our knowledge of porphyrin biochemistry to the fact that certain rather rare disturbances of porphyrin metabolism occur both in man and in animals, and in these conditions excessive quantities of pigments are produced by the body. They are familial diseases. Thus in congenital porphyria, inherited as a Mendelian recessive character, there is from birth a large excretion in the urine and faeces of uroporphyrins and coproporphyrins, belonging mainly to series I, and the tissues of the body also become saturated with porphyrins. Since the porphyrins are strongly photoactive, this condition causes intense photosensitivity in the sufferers. On examination, the bones and teeth are seen to be reddish brown in colour, and under ultra-violet light they fluoresce brilliantly (figures 10, 15, 16, 17). In this disease freshly passed urine also is highly fluorescent because of the uroporphyrins and coproporphyrins it contains (figure 12). Another disturbance of porphyrin metabolism, termed porphyria cutanea tarda, shows many points of resemblance to congenital porphyria. Photosensitivity is again a marked feature, but the condition appears only later in life; porphyrins are produced in excessive quantities, but these are, in general, eliminated in the faeces and do not raise the urinary porphyrin level above normal except during severe transient exacerbations. Photosensitivity is encountered in differing grades of severity, but the crippling deformities of congenital porphyria are rarely seen.

A third disease, acute porphyria, differs in many respects from both congenital porphyria and porphyria cutanea tarda. It is inherited as a dominant character, the highest incidence being in the second or third decade of life, and photosensitivity is never seen. The characteristic symptoms are intense abdominal pain, vomiting, constipation, mental confusion, and, very frequently, progressive paralysis which terminates fatally. In freshly passed urine there is some excess of coproporphyrin, but in place of the uroporphyrin accompanying the other forms of porphyria there is found a colourless, non-fluorescent substance named porphobilinogen, which is transformed on standing into a mixture of uroporphyrins. Porphobilinogen is readily detected, and acute porphyria thus recognized, by treating freshly passed urine with Ehrlich's reagent, a solution of *p*-dimethylaminobenzaldehyde in 5N hydrochloric acid. Figures 11(*a*) and 11(*d*) show respectively urine containing urobilinogen and a urine, from a case of acute porphyria, containing porphobilinogen. A red colour is produced with the reagent if either porphobilinogen or urobilinogen is present; on adding an equal volume of saturated sodium acetate and shaking with chloroform, however, the red compound due to urobilinogen is extracted into the chloroform layer (figure 11(*b*)) while that due to porphobilinogen remains in the aqueous phase (figure 11(*c*)).

The isolation of porphobilinogen has recently been accomplished and it has been shown to be a simple pyrrole derivative (figure 8). On heating in dilute acid it is readily transformed into a mixture of isomeric uroporphyrins in which the series III isomer predominates. This transformation takes place more slowly at room temperature and is hastened by sunlight, so that urine from a case of acute porphyria almost invariably develops uroporphyrin on standing.

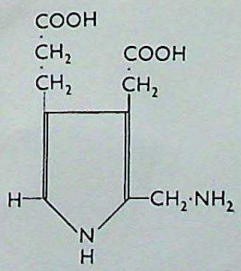


FIGURE 8 – *Porphobilinogen.*

Examination of the organs of a fatal case of acute porphyria shows that porphobilinogen (non-fluorescent) is present in the liver and to a lesser extent in the kidneys and blood; the bone marrow contains neither porphobilinogen nor excessive amounts of porphyrin.



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FIGURE 9 – *Rat with gland of Harder exposed. Ultra-violet light.*

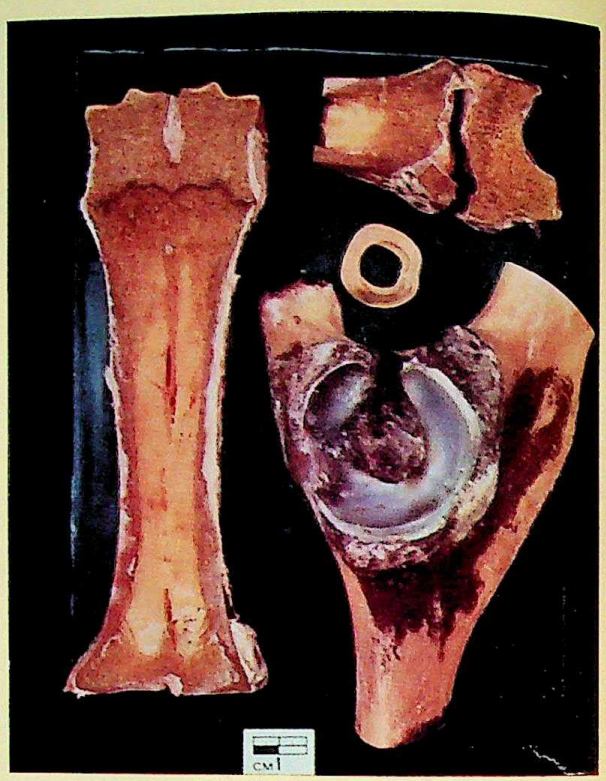


FIGURE 10 – *Congenital porphyria in a South African ox. Bones deeply pigmented with uroporphyrin.*

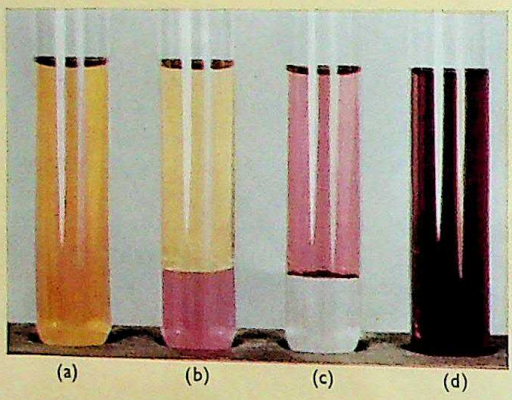


FIGURE 11 (*left*) – *Watson-Schwartz test for porphobilinogen in acute porphyria.*

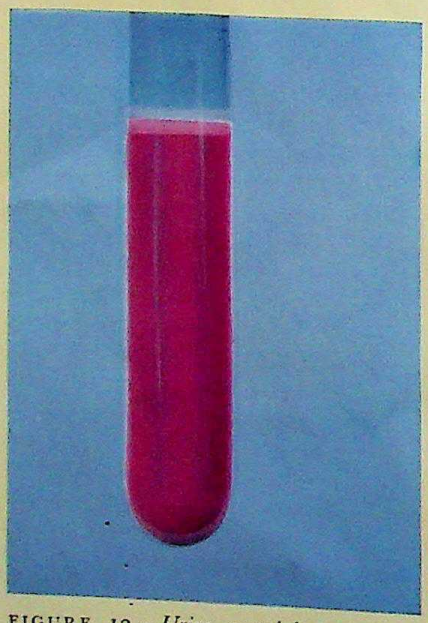

FIGURE 12 – *Urine containing porphyrin, from a case of congenital porphyria. Ultra-violet light.*

FIGURE 13 – *Paper chromatographic separation of porphyrins. Ultra-violet light.*

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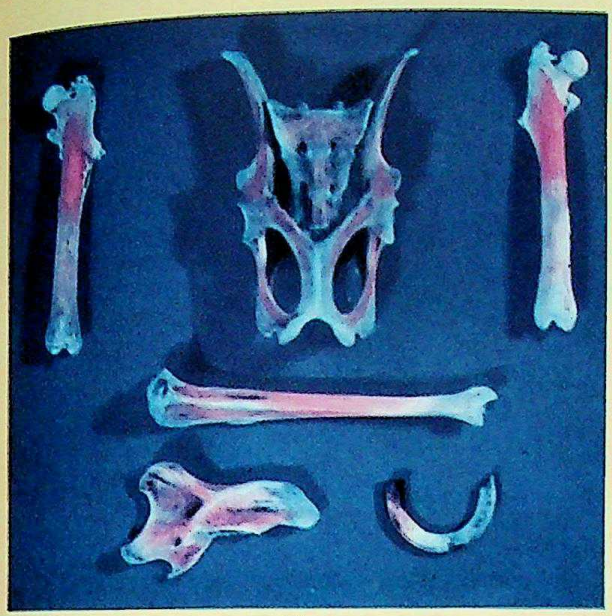
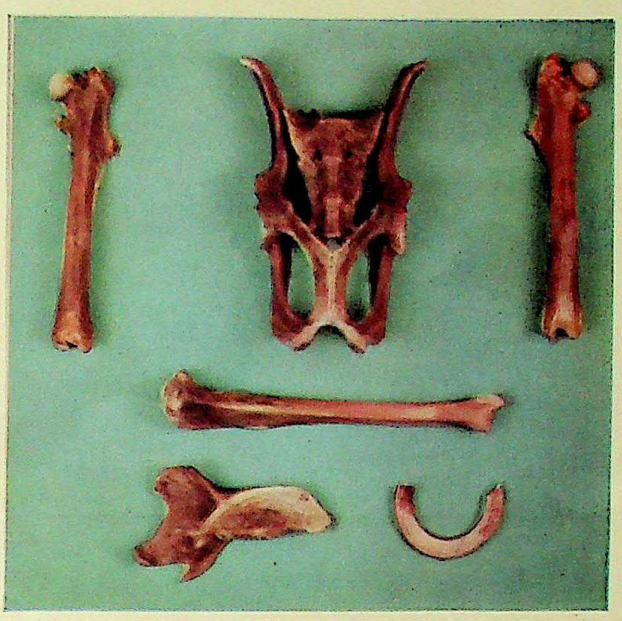


(a)



(b)

FIGURE 14 – *Bones of ground squirrel* (Sciurus niger). (a) *Ultra-violet light.* (b) *White light.*

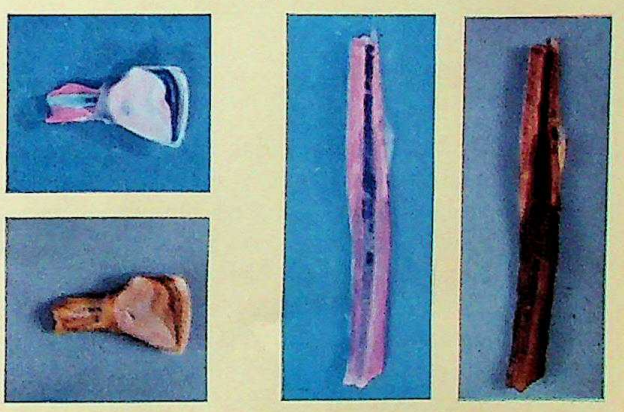


FIGURE 15 (*right*) – *Tooth of ox with congenital porphyria; portion of rib of a pig with congenital porphyria. White and ultra-violet light.* (*Specimens lent by Dr T. K. With, Svendborg, Denmark.*)

FIGURE 16 – *Portion of lower jaw of ox with congenital porphyria. Ultra-violet light.* (*Specimen lent by Dr T. K. With, Svendborg, Denmark.*)

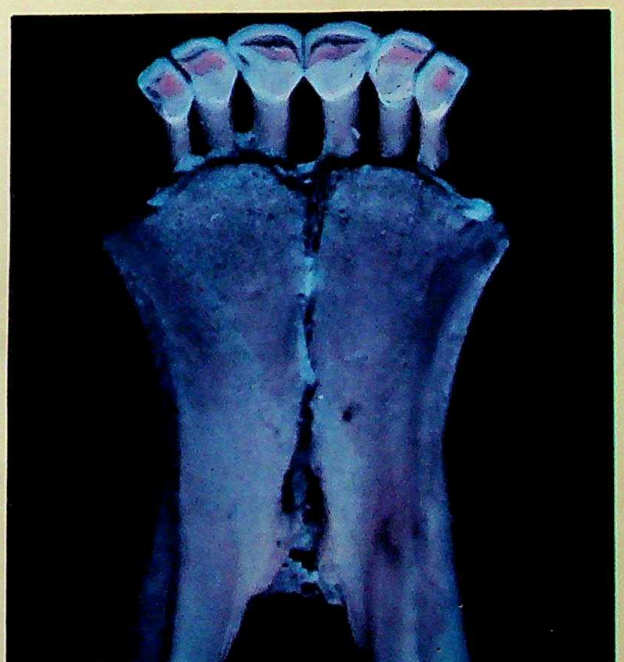


FIGURE 17 – *Upper surface of jaw shown in figure* 16. *Note localized fluorescence due to porphyrin in the teeth. Ultra-violet light.*

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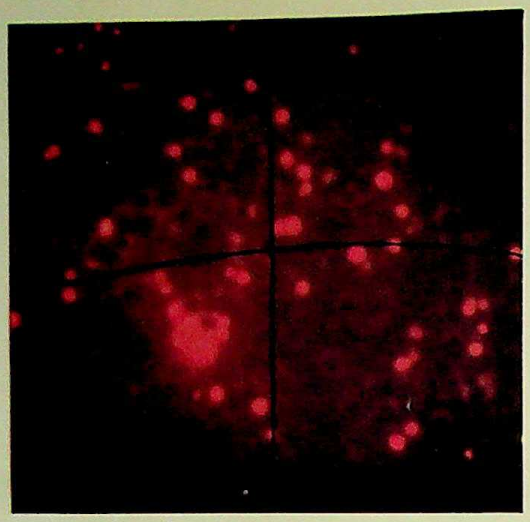

FIGURE 18 – *Bone marrow from a case of congenital (erythropoietic) porphyria in man. Note abundance of cells exhibiting fluorescence due to porphyrin. Ultra-violet light. (Supplied by Professor C. J. Watson and Dr R. Schmid, University of Minnesota.* Arch. intern. Med., **93**, 167, 1954.) (× 260)

FIGURE 19 – *Appearance of blocks of post-mortem liver tissue under ultra-violet light. Left: from cases of congenital (erythropoietic) porphyria. Right: from cases of acute (hepatic) porphyria. Centre: from cases of porphyria cutanea tarda. Note presence of porphyrin only in the latter. (Supplied by Professor C. J. Watson and Dr R. Schmid, University of Minnesota.* Arch. intern. Med., **93**, 167, 1954.)

In congenital porphyria, on the other hand, porphobilinogen is absent and the liver porphyrins are not greatly raised, but the bone marrow contains numerous porphyrin-containing cells of the erythropoietic series which are vividly fluorescent in ultra-violet light (figures 18, 19). In porphyria cutanea tarda the hepatic cells are rich in porphyrin, but contain little or no porphobilinogen. To emphasize the difference in the respective sites of origin of the excessive pigments or their precursors, C. J. Watson has proposed subdivision of porphyria into 'hepatic' and 'erythropoietic' respectively, the former including congenital porphyria and the latter acute porphyria, the cutanea tarda type, and also an experimental porphyria induced by the administration of drugs such as allyl*iso*propylacetylcarbamide, allyl*iso*propylacetamide, and diallylbarbituric acid. All these substances cause the excretion in normal animals of porphobilinogen and of excessive amounts of coproporphyrins in the urine.

### THE BIOSYNTHESIS OF PORPHYRINS AND OF HAEM

Ten years ago nothing was known concerning the steps by which the porphyrins and the haem of haemoglobin are synthesized by living cells. Today the principal steps in the biosynthetic sequence have been revealed, a result largely due to the introduction of isotopic labelling techniques. The first notable achievement was the demonstration by D. Shemin and D. Rittenberg [3] in 1946 that the nitrogen atom of glycine is specifically incorporated into the haem of freshly formed erythrocytes in man. Later, duck blood containing nucleated erythrocytes was found capable of carrying out the same biosynthesis *in vitro*; nearly all subsequent work by the American team has employed this system, while British groups have worked with living rabbits or with chicken red-cell preparations.

In all cases the aim has been to degrade the haem, which was synthesized in the presence of an isotopically labelled precursor, in such a way that the degree of labelling of individual atoms can be measured. This is not completely possible in the case of haem, since pyrrole rings I and II are similar in structure and so are rings III and IV; nevertheless, these pairs may be degraded separately. First, the iron is removed from haem and the vinyl groups of the resulting protoporphyrin are catalytically reduced to ethyl groups, the porphyrin formed being known as mesoporphyrin (see figure 20, in which the individual atoms and rings are identified conventionally, A, B, C, and D being used for the latter, however, to avoid confusion with the numerals denoting atoms). Chromic acid oxidation now ruptures the macrocyclic ring, liberating the bridge carbon atoms as carbon dioxide and affording a molecule of



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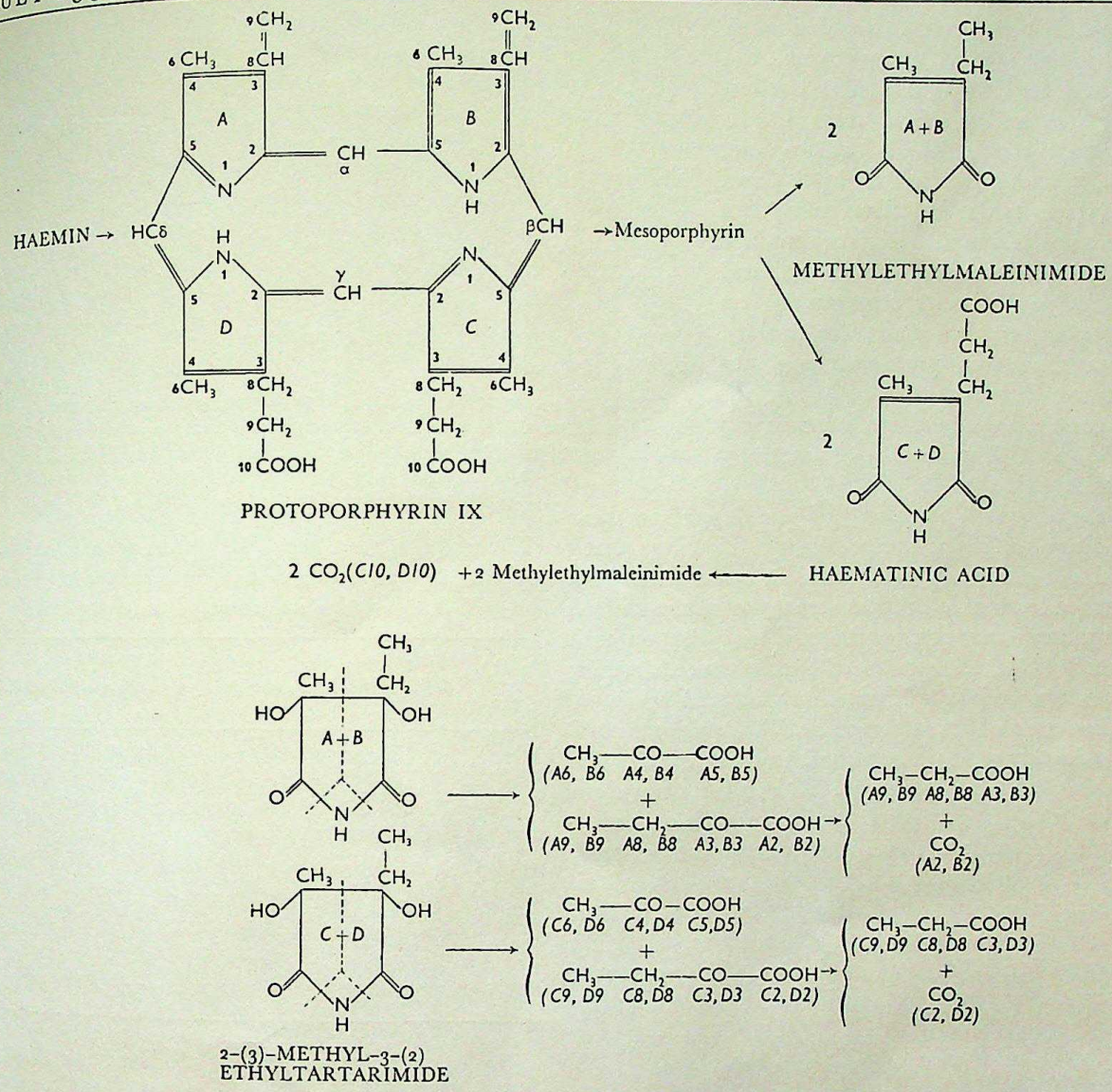


FIGURE 20 – *Degradation of haemin.*

methylethylmaleinimide from each of rings A and B and a molecule of haematinic acid from each of rings C and D. Haematinic acid is decarboxylated by heating to produce a molecule each of carbon dioxide and of methylethylmaleinimide (figure 20). The two lots of methylethylmaleinimide, representing pyrroles A + B and C + D respectively, are separately degraded by the further series of steps shown in figure 20, each carbon atom of the porphyrin thus being finally obtained in the form of carbon dioxide, the radioactivity of which can be measured and compared with that of the $^{14}C$ substrate used in the experiment.

It has been found that all four nitrogen atoms of haem are derived from the nitrogen of glycine, while the methylene carbon atom of glycine contributes all four bridge carbon atoms and one other carbon atom in each pyrrole ring, namely $A_2$, $B_2$, $C_2$, and $D_2$. The carboxyl group of glycine is not incorporated into the porphyrin structure. All the carbon atoms of haem not supplied by glycine can be derived from acetate, but experiments with acetate labelled with radioactive carbon in the carboxyl group or methyl group respectively show that acetate itself cannot be the immediate precursor.

If stepwise degradation is applied to the porphyrin synthesized in the presence of acetate labelled with $^{14}C$ in the carboxyl group, the highest activity is found in the two carboxylic acid groups $C_{10}$ and $D_{10}$ of the porphyrin, although some is present in carbon atoms 3 and 5 of all



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rings. When acetate labelled with $^{14}C$ in the methyl group is used, the highest activity is found in carbon atoms 6 and 9 of all rings but a great deal is found also in positions 4, 8, 5, and 3 and a little in $C_{10}$ and $D_{10}$ (see table I). Evidence that the two halves of the pyrrole rings which give rise to pyruvic acid and α-ketobutyric acid respectively on degradation (figure 20) are derived from the same precursor is forthcoming from equal labelling, each to each, of the position pairs 6 and 9, 4 and 8, 5 and 3 respectively (figure 21).

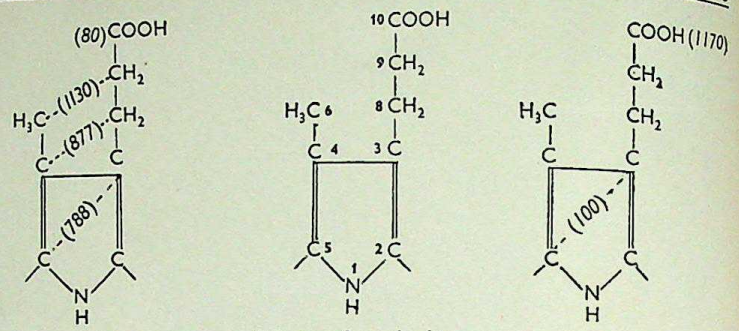


FIGURE 21 – *Average activities, in parentheses, of comparable carbon atoms in all pyrrole units. The pyrrole unit represented contains a carboxyl group, found only in rings C and D of the porphyrin. (After Shemin and Wittenberg [4].)*

Shemin and Wittenberg [4] postulated from these findings that in the course of porphyrin biosynthesis a single precursor of a pyrrolic nature was first formed from union of two unsymmetrical 4-carbon units and one glycine unit. The 4-carbon unit could be a derivative of succinic acid arising from acetate *via* the tricarboxylic acid cycle. If this were so, the precursor of all four rings A to D would carry acetic acid and propionic acid side chains in its ββ′ positions. Union in some way of four units of this pyrrole and four units representing the α carbon atoms of glycine molecules could yield a uroporphyrin. Postulated loss of six carboxyl groups and four hydrogen atoms could then lead to protoporphyrin and so, after the incorporation of iron, to haem. The scheme is summarized below (compiled after Shemin):

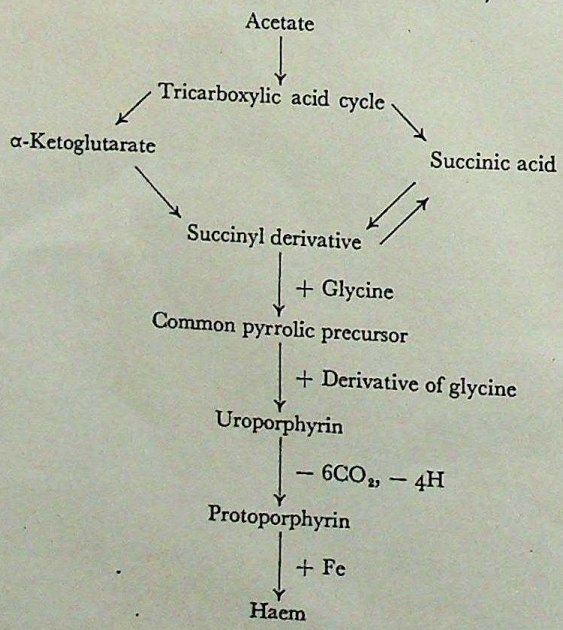


TABLE I

*Total activity (counts per minute) of each of the carbon atoms of protoporphyrin biosynthesized from acetate labelled with $^{14}C$ in the methyl and carboxyl group respectively*

| Carbon number | [methyl-$^{14}C$] acetate | | [Carboxyl-$^{14}C$] acetate | |
|---|---|---|---|---|
| | Rings A + B | Rings C + D | Rings A + B | Rings C + D |
| 2 | 0 | 0 | 0 | 0 |
| 3 | 776 | 767 | 95 | 88 |
| 4 | 973 | 811 | 0 | 0 |
| 5 | 770 | 833 | 109 | 106 |
| 6 | 1210 | 1010 | 0 | 0 |
| 8 | 854 | 869 | 0 | 0 |
| 9 | 1190 | 1130 | 0 | 0 |
| 10 | — | 80 | — | 1260 |

The fact that the addition of coenzyme A to an avian blood system increases the utilization of succinate for porphyrin formation *in vitro* suggests that the unsymmetrical succinyl derivative may be succinyl coenzyme A, but no direct evidence in support of this is as yet forthcoming.

When pure porphobilinogen became available and G. H. Cookson and C. Rimington [5] had shown that it was a pyrrole derivative (figure 8) carrying the same side chains in the β and β′ positions as are present in the pyrrole rings of uroporphyrin (figure 7), its possible relation to normal porphyrin biosynthesis became obvious.

It was shown by J. E. Falk, E. I. B. Dresel, and C. Rimington [6] that porphobilinogen added to an avian red-cell haemolysate could serve as a substrate for porphyrin production. Proof that it was, in fact, the 'common pyrrolic precursor' of the above scheme and a true intermediate in normal porphyrin biosynthesis, followed from the



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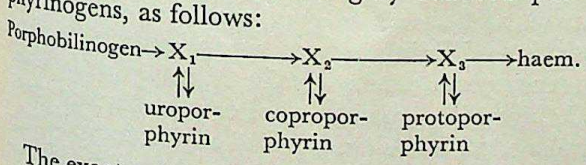
further demonstration that radioactive porphobilinogen could be isolated from a haemolysate utilizing radioactive glycine as substrate. Since glycine and succinic acid had already been established as raw materials for the synthesis of porphyrins, it became clear that some structure derived from their union must intervene between them and porphobilinogen in the train of chemical events. Shemin and C. S. Russell [7] in America, and almost simultaneously A. Neuberger and J. J. Scott [8] in England, identified this structure as δ-aminolaevulic acid. According to Shemin, glycine and 'active' succinate first combine to form α-amino-β-ketoadipic acid, which, being a β-ketonic acid, readily loses carbon dioxide (hence the absence of the carboxyl carbon of glycine from the final porphyrin structure) to yield δ-aminolaevulic acid. Neuberger's group have purified the enzyme which condenses two molecules of δ-aminolaevulic acid and produces porphobilinogen. The process is shown in figure 22.

So far, little has been said concerning the position of uroporphyrin, coproporphyrin, and protoporphyrin in the biosynthetic pathway leading to haem. They would appear to be logical steps, but the evidence is rather conflicting. Certainly red-cell haemolysate systems can bring about some porphyrin interconversions, but they do so rather inefficiently, and radioactive labelling data show that much better biosynthesis results when either glycine and succinate, δ-aminolaevulic acid, or porphobilinogen acts as substrate. Considerations of the permeability of the sub-cellular particles may be responsible for this difference. Alternatively, it is possible that the porphyrins are not on the direct line of biosynthesis but are produced by reversible side reactions from closely related precursors, possibly the more highly reduced porphyrinogens, as follows:




The exact nature of the porphyrins produced in these systems and the isomeric series to which each belongs is at present being very carefully investigated by paper chromatographic and other techniques. Figure 13 illustrates the use of paper chromatography for this purpose. (1–3) are uroporphyrins from *in vitro* biosyntheses; (4–5) coproporphyrin III from a similar source; (6) markers, respectively uroporphyrin I (on left), coproporphyrins I, III, and II, and deuteroporphyrin IX; (7) coproporphyrin III produced by decarboxylating uroporphyrin; (8–10) uroporphyrins from *in vitro* biosyntheses. Before long, the entire chain of events by which the body synthesizes its vital haem and porphyrin pigments should become known, and possibly also the nature of the chemical aberrations which are responsible for porphyria diseases of man and animals.

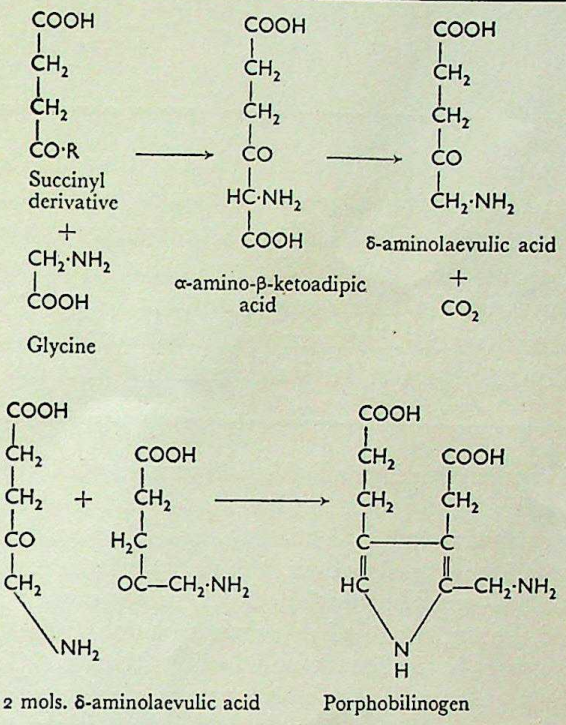



FIGURE 22 – *Scheme summarizing biosynthetic steps from glycine + succinate (from the tricarboxylic acid cycle) to porphobilinogen, the simplest pyrrolic substance known to be a precursor of haem and porphyrins.*

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# George Johnston and the Ray Society

C. M. YONGE

Natural history societies have long made valuable contributions to biology, and in this year fall two important anniversaries in their history. It is the 250th anniversary of the death of John Ray, among the greatest of British naturalists, and the 100th anniversary of the death of George Johnston, founder of the Ray Society and a noteworthy representative of the early nineteenth-century naturalists who did so much to establish the identity and distribution of British species of plants and animals. The Ray Society is internationally known for its beautifully illustrated volumes dealing with British natural history.

Linnaeus inspired a fashionable interest in natural history in the eighteenth century. His method of description and of naming, and his system of classification—however artificial this later proved to be—appealed to the orderly minds of that age of reason. A further stimulus came from the voyages in the Pacific and Indian Oceans of Cook and other explorers who brought home a wealth of new plants and animals. These were all named and classified, and then found their way into national museums or into the cabinets of wealthy aristocratic collectors.

Apart from Linnaeus, the leading naturalist in Europe at that time was George Louis Leclerc, Comte de Buffon. No gentleman's library was complete without his magnificently illustrated *Histoire naturelle*. In Britain Sir Joseph Banks guided the development of natural history with as much authority as he did that of the Royal Society. The first 'British Zoology' was produced, in the intervals between his numerous tours, by Thomas Pennant, a country gentleman of liberal means. His friend and correspondent, Gilbert White, with little money but with leisure and cultured interest, built a more enduring monument within the narrow confines of Selborne.

We know less of John Ellis, who revealed the purely animal nature of zoophytes and helped to describe the corals collected by Cook, but he was of sufficient consequence to be asked to display his collections to the Princess of Wales. Colonel George Montagu, a somewhat later figure, was a gentleman of wealth who retired from the army to study the animals of Britain's western shores and to write books on birds and molluscs. The few who made a living, as opposed to a hobby, out of natural history did so by catering to the taste for illustration. Edward Donovan serves as an example; his books on birds, fishes, molluscs, and insects have little beyond the beauty of their plates to commend them.

As the nineteenth century advanced the influence of the landed gentry began to decline, while that of the middle classes rose. The wider spread of education and of some measure of wealth and leisure were reflected in a wider interest in natural history and, in particular, in the plants and animals of the countryside, shore, and sea. The ranks of the amateur naturalists were reinforced by professional men, in particular doctors and clergymen, and by small merchants and shopkeepers. Later in the century came the self-taught artisans like William Peach, Hugh Miller, and Thomas Edward. Gradually there emerged the professional zoologist and botanist, although for much of the nineteenth century material reward was as meagre as enthusiasm and achievement were great.

Of these new naturalists, George Johnston stands out as a truly representative figure well worthy of remembrance. The tenth of a family of fifteen, he was born on a farm at Simprin in Berwickshire, on 27th July, 1797. He was educated at Berwick before proceeding to the University of Edinburgh to study medicine. When twenty years old he obtained the diploma of the College of Surgeons, and after some further study in London, and a brief period of practice in Northumberland, he settled permanently in Berwick-on-Tweed. He built up the largest medical practice in Berwick and the surrounding countryside, and became a familiar and much-loved figure.

He devoted every available moment to the study of natural history, on which he wrote many papers and several books. He conducted a voluminous correspondence with contemporary naturalists and much of this has, most fortunately, been preserved and published. A book of 'Selections from the Correspondence of Dr George Johnston,



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FIGURE 1 – *Dr George Johnston, from a photograph taken in later life.*

collected and arranged by his daughter, Mrs Barwell-Carter, appeared in 1892, to celebrate the sixtieth anniversary of the foundation of the Berwickshire Naturalists' Club.

These letters form a volume of over 500 pages, and are addressed largely to naturalists. They include P. J. Selby, the ornithologist; Joshua Alder of Newcastle, who was part-author of 'The British Nudibranchiate Mollusca'; William Thompson, of Belfast, who died too early to produce more than the early volumes of a projected natural history of Ireland; the Reverend David Landsborough of Saltcoats, Ayrshire, the author of 'Excursions to Arran' and various books on marine biology; Charles William Peach, at that time in the customs office at Fowey; and also local naturalists such as James Hardy and Archibald Hepburn. Interspersed with these are letters to his publishers, W. H. Lizard of Edinburgh and John Van Voorst of London, while in later years many are addressed to Mrs Alfred Gatty, author of 'Parables of Nature' and of many books for children, who shared his interest in the natural history of seaweeds.

Almost every contemporary British naturalist is mentioned in these letters. Although Mrs Barwell-Carter arranged the letters, they were edited by James Hardy, at that time honorary secretary of the club, who greatly increased the value of the book by his informative footnotes dealing with almost every person mentioned. Letters and notes together form a mine of information about British naturalists and their activities between 1830 and 1853.

The Berwickshire Naturalists' Club, the first provincial society of its kind in Britain, was founded in 1831 'for the purpose of examining the Natural History and Antiquities of the county and its adjacent districts and of affording to such as were interested in these objects, the opportunity of benefiting by mutual aid and co-operation.' There were initially eleven members, and Johnston was the founder and first president. The letters do not deal with the foundation of the club, but its later activities are frequently mentioned. Johnston had clear views about the functions of such societies. Writing to Joshua Alder, he declines the offer of a mere catalogue of the names of local molluscs, 'believing as I do that it is the prime business or duty of provincial societies to furnish their members with the means of investigating the natural history of their own district without sending them to other works or museums.'



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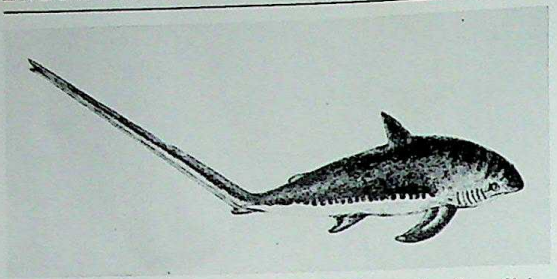

FIGURE 2 – *Long-tailed shark. An illustration from Johnston's description of a specimen captured at Berwick in* 1846, *and published in the 'History of the Berwickshire Naturalists' Club.'*

FIGURE 3 – *Sea anemone,* Bolocera tuediae *(Johnston), described (as* Anthea tuediae*) in 'A History of the British Zoophytes.'*

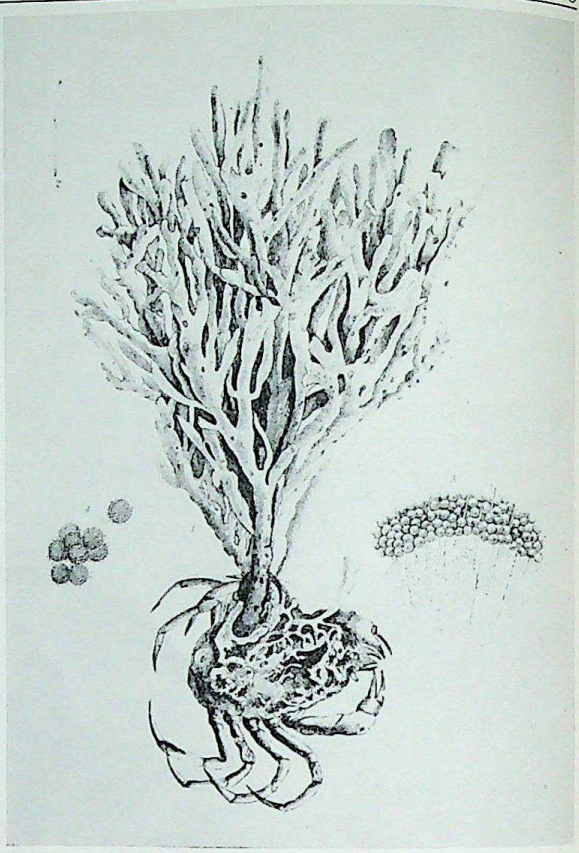

FIGURE 4 – *Sponge growing on the back of a spider crab, figured in 'A History of British Sponges and Lithophytes.'*

In 1834 he sends a full account of a meeting to a member who had been absent. 'A paper by William Baird on the Berwickshire Entomostraca was read. He knows already more Berwickshire species of these very curious creatures than have been yet enumerated as British, and the paper, when completed, promises to be a most interesting one. . . . I then exhibited some Birds, Fishes, and Insects, which had been taken lately in Berwickshire. . . . The Grey Phalarope was among the birds. Embleton again brought the Crabs and Lobsters of the coast before us, naming them from my collection, in which there were six additional species to his list, and a fine species of *Galathea*, which I think is new. . . . I now exhibited a collection of the Bivalved Shells of the coast, and read a paper on them. . . .'

The letters, with their descriptions of such meetings, and of inquiries and discussions about specimens of all kinds, show clearly that Johnston and his contemporaries were working their way through the local fauna and flora, puzzling out the identity of animals and plants that are now familiar. All the time they were adding new species to their local lists and so building up that knowledge about the nature and distribution of British species which was the particular contribution of these early nineteenth-century naturalists.

There is no concern with biological evolution. The 'Origin of Species' was not published until four years after Johnston died, and he had clearly no thought but that all forms of life originated from a beneficent and endlessly ingenious Creator. He was a describer of species and an observer of habit and distribution, but he was no comparative anatomist. On several occasions, when he is tempted to apply for academic posts, this ignorance of internal structure is realized to be a drawback. He admits that he 'was educated in an earlier school, and am not likely ever to rise above, if I could even equal, my masters: these were Pennant and Montagu, who have merit certainly, but they were the founders of the school of superficiality.' Certainly no major discovery came from Johnston, but he was receptive to those of others. After going to much trouble to confirm



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them, he accepts Grant's description of the water currents in sponges and the discovery by Vaughan Thompson, revolutionary in its day, that barnacles are not molluscs but crustaceans.

Johnston wrote five books. An early 'Flora of Berwick' (1829–31); 'A History of British Zoophytes' (first edition, 1838; second edition, 1847); 'A History of British Sponges and Lithophytes' (1842); 'An Introduction to Conchology' (1850); and finally 'The Natural History of the Eastern Borders,' of which only the first volume, dealing with botany, appeared (1853). None are works of the first importance, although the book on zoophytes was the first published upon them since that of John Ellis in 1755. It represents a stepping stone between that book and the later volumes of Gosse, Allman, Hincks, and, most recently, Stephenson. Today, the most readable section is the chapter on the history of 'zoophytology.' The book on conchology was praised by Edward Forbes and was even translated into German, but it is no more than an interesting compilation about shells and their inhabitants. 'The Natural History of the Eastern Borders' was to have been his crowning work, and it is sad that only one volume was completed; this is full of interesting local information. The club published, and still publishes, its 'History' which he edited, and he was also part-editor of a short-lived 'Magazine of Zoology and Botany'; this merged into the 'Annals and Magazine of Natural History,' which continues to appear.

There is little doubt, however, that Johnston's name will always be remembered primarily in connection with the foundation of the Ray Society. First mention of this in the 'Correspondence' is in a letter to James Hardy, dated 20th February, 1843. But he is soon writing to all his friends on the subject, begging them to help by interesting others. After discussing the difficulties of publishing books on natural history at a reasonable price, he writes: 'I have long wished to propose to establish a Ray Society, at an annual subscription of one or two sovereigns, to print works illustrative of the Natural History of Great Britain, original and old.' And later, in an almost impassioned letter to William Thompson, he writes that with the establishment of this society 'I shall see the neglected corners of our Fauna and of our Flora searched out. . . . Natural History is a good study and a wholesome one, and the meat and medicine have been too long dispensed only to the rich. . . . It is because I am poor that I plead for the Ray Club.'

In the obituary of Sir William Jardine, published in the 'History' of the Berwickshire Naturalists' Club, of which he was at one time president, some credit for the foundation of the Ray Society is given to Hugh Strickland, his son-in-law. The latter certainly assisted Johnston by distributing circulars and collecting members. It was hoped to secure five hundred members, but after initial optimism Johnston had a period of despair. However, there was little reason for this, because by April 1844 he was able to report that the Ray Society had made a beginning. By September of the same year it had assumed 'a more healthy appearance. It has increased considerably of late, and we have one large volume in the press, which will be ready about Christmas.'

In point of fact, such was the interest that his enthusiasm inspired that considerably over five hundred members were enrolled within the first year. Johnston had done a major and an enduring service to the cause of natural history. During the 111 years that have elapsed since its foundation, the Ray Society has published some 140 volumes, dealing with every aspect of British natural history —from protozoans to whales, from lichens to mites and barnacles. Many of these monographs rank high among similar works in any language. The society's highest membership, 868, was attained within five years of its foundation, after which numbers slowly declined until they fell to less than two hundred in the years between the two world wars. There was a real danger that the society would have to be wound up during the last war, but this was fortunately averted owing to generous donations, particularly from Imperial Chemical Industries Limited. Membership has since increased, and it is now well over four hundred. Johnston would view with much happiness the hopeful prospects, in its second century, of the society he did so much to establish.

After settling down in practice in Berwick Johnston rarely left home. Writing in 1853, he says that 'during the thirty-five years I have been in Berwick I have not had six weeks' holiday in all, rather, I should say it has been one grand holiday; . . . ' The esteem in which he was held is shown by the long period for which he served as Alderman and by the fact that he was thrice elected Mayor. These activities he certainly enjoyed, but probably most of all he loved the meetings of the club he had founded and their excursions—perhaps to Holy Island with its prospect of 'the priory, and church, and castle, and Bamborough Castle, and the Farne Islands, and the sea, the glorious sea, . . .' He died in 1855.



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# Organic compounds of the metals

W. WARDLAW and D. C. BRADLEY

The chemistry of organometallic compounds presents many points of practical as well as theoretical significance. Within the last few years the silicones, for example, which less than twenty years ago seemed to be of only academic interest, have become of very considerable industrial importance. Organic compounds are likely to prove useful for the purification of some of the rarer elements, such as zirconium, which have lately become of interest to engineers.

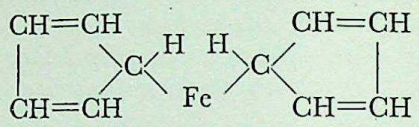
Organic derivatives of metals and metalloids have long been known, and their study has led to many important developments in both pure and applied chemistry. Compounds containing carbon directly linked to a metallic element are now often termed organometallic, to distinguish them from the wider class of organic compounds of the metals which need not contain metal-carbon bonds.

The great importance of organomagnesium compounds was first recognized by Grignard in 1900. An unusual use of the Grignard reagent is in the preparation of the aromatic hydrocarbon diphenyl, made by the action of phenyl magnesium bromide on anhydrous ferric chloride.

$$6C_6H_5MgBr + 2FeCl_3 = 2Fe + 3MgBr_2 + 3MgCl_2 + 3C_{12}H_{10} \text{ (diphenyl)}.$$

T. J. Kealy and P. L. Pauson [1] used this method in an attempt to prepare the hydrocarbon fulvalene ($C_{10}H_8$), and discovered a remarkable new compound which contained only carbon, hydrogen, and iron. By reaction between ferric chloride and cyclopentadienyl magnesium bromide ($C_5H_5MgBr$) they hoped to obtain dicyclopentadienyl ($C_{10}H_{10}$) as an intermediate step to their goal. They isolated instead an orange, ether-soluble compound of iron, having m.p. 172·5–173° C and the formula $Fe(C_5H_5)_2$. It had great chemical stability and concentrated nitric acid was required to decompose it. Further work [2] revealed that it volatilized without decomposition into a monomeric, undissociated vapour which obeyed the perfect-gas laws even at 400° C.

G. Wilkinson, M. Rosenblum, M. C. Whiting, and R. B. Woodward [4] found that the compound was diamagnetic and without appreciable dipole moment. In addition they examined its optical absorption spectrum and concluded that the substance contained only one type of C—H bond, in opposition to the structure (I) proposed by Kealy and Pauson.




(I)

They suggested the sandwich structure shown in figure 1, and X-ray studies by three groups of workers [5] have confirmed their views.

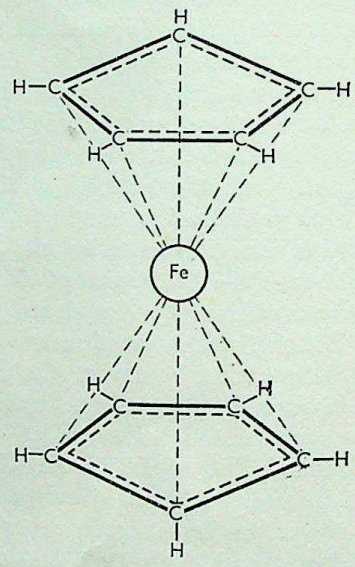



FIGURE 1

Further research [4] disclosed that the compound was readily oxidized in solution to a bright blue cation $[Fe(C_5H_5)_2]^+$, which was isolated as the crystalline tetrachlorogallate.

Woodward, Rosenblum, and Whiting [6] discovered that the compound would participate in the Friedel-Crafts reaction and that the ring hydrogen was substituted without affecting the metal atom.

$$Fe(C_5H_5)_2 + 2CH_3COCl \xrightarrow{Al_2Cl_6} Fe(C_5H_4.COCH_3)_2 + 2HCl.$$

This elegant demonstration of the aromatic character of iron biscyclopentadienyl led to the suggestion that the compound should be named



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ferrocene. Attention was then directed to the preparation of similar derivatives of other transition metals. In the space of two years cyclopentadienyl derivatives of most of the transition metals have been made by Wilkinson and his collaborators at Harvard University, and by E. O. Fischer and his collaborators at Munich. Some examples of these compounds are given in table I.

In addition to the above compounds, some analogous compounds of indene have been prepared, such as $Fe(C_9H_7)_2$, $[Co(C_9H_7)_2]^+$, and $Ni(C_9H_7)_2$. The table shows that the formation of stable biscyclopentadienyl derivatives seems to be a typical property of the transition metals.

In the structure established for the ferrocene molecule the interatomic distance for the carbon atoms in the rings is 1·4 A, in accord with aromatic substances generally. For ferrocene and the other biscyclopentadienyl metal derivatives there is a characteristic infra-red absorption at 3·27 μ corresponding to a single C—H bond-stretching, which is typical of C—H bonds in aromatic systems. This suggests that all compounds such as those shown in table I have similar structures. Magnetic measurements [8] have yielded valuable information about the electronic arrangements in these new substances. Many, such as $Fe(C_5H_5)_2$ and $[Co(C_5H_5)_2]^+$, are diamagnetic, but others, for example $[Fe(C_5H_5)_2]^+$ and $Co(C_5H_5)_2$, are paramagnetic, consistent with the presence of a single unpaired electron. $[V(C_5H_5)_2]^+$, $Cr(C_5H_5)_2$, and $Ni(C_5H_5)_2$ are paramagnetic and the results indicate the existence of two unpaired electrons in each ion or molecule.

Measurements of the heats of combustion of ferrocene and of biscyclopentadienyl nickel [9] indicate that the nickel compound has the smaller thermodynamic stability.

Wilkinson and J. M. Birmingham [10] have shown that when present in these metal-organic systems the metals of Groups IVA and VA still retain 'transitional' properties.

A common property of the biscyclopentadienyl cations is the formation of insoluble salts with large anions such as picrate, ferrocyanide, and silicotungstate.

The methods developed for the preparation of the biscyclopentadienyl compounds may be considered under four headings:

1. Reactions of metal halides or acetylacetonates with either cyclopentadienyl magnesium halide or cyclopentadienyl sodium. This method has been extensively used by Wilkinson and his collaborators, e.g:

$$TiCl_4 + 2NaC_5H_5 \rightarrow Ti(C_5H_5)_2Cl_2 + 2NaCl.$$

2. Reaction of a complex metal ammine with either lithium, sodium, or potassium cyclopentadienyls in liquid ammonia, followed by thermal dissociation of the metal ammine cyclopentadienyl. This method was devised by Fischer and his collaborators [11], e.g:

$$Co(NH_3)_4(SCN)_2 + 2KC_5H_5 \xrightarrow{\text{liq. } NH_3} Co(NH_3)_4(C_5H_5)_2 + 2KSCN.$$

$$Co(NH_3)_4(C_5H_5)_2 \xrightarrow{\text{Heat}} Co(C_5H_5)_2 + 4NH_3.$$

3. Reaction of iron and cyclopentadiene [3]:

$$Fe + 2C_5H_6 \xrightarrow{375^\circ C} Fe(C_5H_5)_2 + H_2.$$

4. Wilkinson [7, 9] has reported a method which involves vapour phase reaction between a metal carbonyl and cyclopentadiene. The carbonyls of chromium, iron, cobalt, and nickel can all be converted to the neutral biscyclopentadienyls, e.g. $Cr(CO)_6$ to $Cr(C_5H_5)_2$. In the cases of molybdenum or tungsten

TABLE I

| Group | | | | |
|---|---|---|---|---|
| *IVA* | *VA* | *VIA* | *VIIA* | *VIIIA* |
| $Ti(C_5H_5)_2$<br>$Ti(C_5H_5)_2^+$<br><br>$Ti(C_5H_5)_2X_2$<br>(X = F, Cl, Br, or I)<br>$Ti(C_5H_5)_2(OH)Br, H_2O$<br>$Zr(C_5H_5)_2Br_2$ | $V(C_5H_5)_2^+$<br>$V(C_5H_5)_2X_2$<br>(X = Cl or Br)<br>$Nb(C_5H_5)_2Br_3$<br><br>$Nb(C_5H_5)_2(OH)Br_2$<br>$Ta(C_5H_5)_2Br_3$ | $Cr(C_5H_5)_2$<br>$C_5H_5Mo(CO)_5MoC_5H_5$<br><br>$[(C_5H_5)_2Mo^{IV}Cl][Cr(CNS)_4(NH_3)_2]H_2O$<br>$Mo(C_5H_5)_2Cl_2$<br>$[(C_5H_5)_2Mo^{V}Cl_2]_2[PtCl_6]$<br>$[(C_5H_5)_2W^{V}Cl_2]_2[PtCl_6]$ | $Mn(C_5H_5)_2$ | $Fe(C_5H_5)_2$<br>$Fe(C_5H_5)_2^+$<br>$Ru(C_5H_5)_2$<br>$Ru(C_5H_5)_2^+$<br>$Co(C_5H_5)_2$<br>$Co(C_5H_5)_2^+$<br>$Rh(C_5H_5)_2^+$<br>$Ir(C_5H_5)_2^+$<br>$Ni(C_5H_5)_2$<br>$Ni(C_5H_5)_2^+$ |



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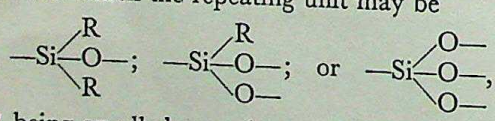
carbonyls, the remarkable cyclopentadienyl carbonyls were isolated, e.g.

$$2Mo(CO)_6 + 2C_5H_6 \rightarrow C_5H_5Mo(CO)_5MoC_5H_5 + CO, \text{ etc.}$$

Earlier discoveries in the field of organometallic chemistry posed problems in valency theory and this has certainly been true with respect to the metal biscyclopentadienyls. The electronic configurations of these compounds has clearly revealed the limitations of current theories, but this fact will no doubt act as a stimulus [8, 12].

The new compounds which have just been discussed are as yet of academic interest only. However, the organic silicon compounds to which Kipping, at Nottingham, devoted his attention from 1899 to 1939 are now of wide industrial application. At no time did Kipping consider that the materials he had made would have any commercial value. His view was expressed in 1937 in the Bakerian Lecture to The Royal Society [13] when he said 'the prospect of any immediate and important advance in this section of chemistry does not seem to be very hopeful.' Yet by the late thirties American interests were examining the possibilities of commercial production of some of the products regarded by Kipping as of little value. A company to manufacture organic silicon compounds was formed in 1943. Recently a new industry based on these remarkable chemical compounds has been started in Britain. The substances concerned are the silicones. The name was used originally to describe compounds of the empirical formula $R_1R_2Si{=}O$, since these were expected to be analogous to the ketones $R_1R_2C{=}O$. This empirical formula can denote an infinite number of compounds, and the term silicone is now generally applied to all organo-silicon compounds having at least one Si—O—Si group. The silicones consist of chain, ring, or cross-linked chain polymers in which the repeating unit may be



R being an alkyl or aryl group. Methyl silicones are the most important (for detailed information consult references [14] and [15]). The mode of formation of the silicones can best be understood by considering the mechanisms of hydrolysis of the three key types of organosilicon compound: $R_3SiX$, $R_2SiX_2$, and $RSiX_3$, where R is an alkyl or aryl group and X is chlorine or ethoxy.

Trimethyl-chlorosilane $(CH_3)_3SiCl$ is readily hydrolysed to the unstable silanol, $(CH_3)_3SiOH$, which itself condenses to form a stable compound, $(CH_3)_3Si{-}O{-}Si(CH_3)_3$, which boils at 99·5° C:

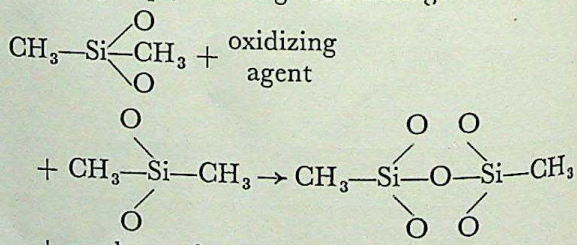
$$(CH_3)_3SiCl + H_2O \rightarrow (CH_3)_2SiOH + HCl$$
$$2(CH_3)_3SiOH \rightarrow (CH_3)_3Si{-}O{-}Si(CH_3)_3 + H_2O.$$

Triaryl chlorosilanes can be converted into triaryl silanols. These compounds, e.g. $(C_6H_5)_3SiOH$ (m.p. 150–151·5° C), are relatively stable and easily isolated. The stability of the carbon-silicon bonds in organosilicon compounds and of the siloxane grouping Si—O—Si accounts for the stability of the silicones.

The hydrolysis of $(CH_3)_2SiCl_2$ leads to the formation of the very unstable dimethyl-silanediol $(CH_3)_2Si(OH)_2$. Again, the corresponding aryl derivatives, such as $(C_6H_5)_2Si(OH)_2$ (m.p. 148° C), are much more stable than the alkyl compounds. The following equation illustrates the type of condensation which may occur:

$$2(CH_3)_2Si(OH)_2 \rightarrow HO.(CH_3)_2Si{-}O{-}Si(CH_3)_2OH + H_2O$$

The hydrolysis of $RSiX_3$ will obviously lead to complex products and, in general, hard brittle solids are ultimately obtained. By varying the proportions of reactive intermediates and the conditions of hydrolysis, however, a wide range of silicones may be obtained; these include mobile non-volatile liquids, highly viscous greases, and hard brittle resins. The products can be further modified by chemical treatment. For example, by the action of ferric or aluminium chloride the linear polymers are converted into rubberlike gels which will undergo cross-linking when subjected to oxidation by organic peroxides. It is believed that the oxidation process involves the elimination of methyl groups, allowing cross-linkage to occur:




+ products of oxidation.

The outstanding development in silicon chemistry in recent years is the discovery by W. I. Patnode and E. G. Rochow [16] in 1945 of a method of preparing organosilicon intermediates directly from silicon and alkyl halides. In this direct synthesis the vapour of alkyl or aryl halide is passed over a heated, finely divided mixture of silicon with either copper or silver. Various alkyl or aryl chlorosilanes are formed. When methyl



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chloride is used with a silicon-copper mixture in the temperature range 250–280° C, the products consist chiefly of $CH_3SiCl_3$ (b.p. 66° C) and $(CH_3)_2SiCl_2$ (b.p. 70° C), together with some $(CH_3)_3SiCl$ (b.p. 57·6° C) and $CH_3SiHCl_2$ (b.p. 42° C). The separation of these products presents a difficult problem, for their boiling points lie close together; in addition the substances are inflammable, toxic, and corrosive.

In general, it is the unusual physical properties of silicones which have determined their special uses. The dimethylsiloxane polymers,

$$(CH_3)_3Si—O—[Si(CH_3)_2—O]_n—Si(CH_3)_3,$$

are colourless fluids ranging from mobile volatile lower members to non-volatile highly viscous long-chain compounds. Silicone rubber far surpasses other elastic materials in its resistance to heat and oxidation, and its elasticity is maintained over the remarkably wide temperature range −90° C to 250° C. Nevertheless, the chemicals that swell ordinary rubber also swell silicones. The most striking property of a silicone fluid is its very low temperature-coefficient of viscosity. This behaviour suggests that intermolecular forces in silicones are abnormally weak—a view that is confirmed by the low surface tensions and high compressibilities of silicones. In addition, silicones are strongly water repellent, and this property, combined with admirable dielectric behaviour and high thermal stability, has established a place for silicones in the electrical industry. For the dimethyl silicone polymers the dielectric constant approaches a limiting value of c 2·82 as the length of the polymer chain increases ($n > 500$). These fluids have high dielectric strengths (c 100–120 kV/cm at 0·254 mm to 200 kV/cm at 2·54 mm). The volume resistivity is high (c $10^{14}$ ohm.cm) and remains sensibly constant up to 200° C. In addition, power factors are low and not appreciably affected by temperature or frequency of applied electric field. Thus power factors vary from 0·0001 at $10^3$ c/s to 0·0006 at $10^8$ c/s. The performance of glass and ceramic insulators is improved by a thin coating of silicone fluid, which prevents the formation of a coherent layer of water under humid conditions. Silicone fluids prevent surfaces of various materials from sticking and they are used extensively as mould-release agents in metal die-casting. The ability of films of silicones to repel water has been utilised in the waterproofing of clothing, and in making furniture and motor-car polishes.

Silicone fluids are essentially linear polymers, but by the introduction of a certain degree of cross-linking silicone greases are obtained. Research workers are finding that silicone greases are invaluable for lubricating stopcocks or ground glass joints in high vacuum systems ($10^{-6}$ mm. Hg). The silicone resins resist oxidation, ultra-violet light, and chemical fumes. Masonry, concrete, and brickwork are made more durable by treatment with them.

The discovery of the remarkable properties of the silicones has stimulated research into the organic compounds of related elements. Germanium, lead, and tin form alkyl and aryl derivatives, but no products analogous to the silicones have been reported. Recently the preparation of unstable alkyl and aryl compounds of titanium was announced [17].

So far in this article, attention has been directed to organic derivatives of the elements in which the element is directly linked to the carbon. Mention should, however, be made of an important group of substances known as the orthoesters or alkoxides, in which the link with the central atom is through the oxygen atom in the OR radical, where R is methyl, ethyl, etc. Such substances as the silicon esters and titanium esters, $Si(OR)_4$ and $Ti(OR)_4$, find wide use in industry and have a fascinating chemistry. In recent years a detailed study has been made of a wide range of the metal alkoxides and the results are of unusual interest [18].

Although silicon and titanium are members of the same family of chemical elements they show marked differences in their own reactions and in the reactions of their compounds. The reaction between silicon tetrachloride and alcohol proceeds to completion in accordance with the equation

$$SiCl_4 + 4EtOH \rightarrow Si(OEt)_4 + 4HCl$$

Titanium tetrachloride, on the other hand, is converted under the same conditions to

$$Ti(OEt)_2Cl_2.EtOH,$$

which is stable even on prolonged boiling with alcohol. Preparation of the orthoester involves reaction between titanium tetrachloride and alcohol in the presence of anhydrous ammonia.

$$TiCl_4 + 4ROH + 4NH_3 = Ti(OR)_4 + 4NH_4Cl.$$

Butyl orthotitanate is made commercially by this method, and confers upon paints excellent heat-resisting properties. Zirconium shows important relationships to both silicon and titanium, yet it is distinctive in being capable of exhibiting a covalency of eight: the maximum covalency exhibited by silicon and titanium is six. The high



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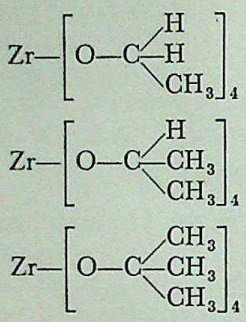
covalency of zirconium is reflected in the range and complexity of its compounds. Zirconium ethoxide is formed when alcohol and zirconium tetrachloride react in the presence of ammonia.

$$ZrCl_4 + 4ROH + 4NH_3 \rightarrow Zr(OR)_4 + 4NH_4Cl.$$

An outstanding feature of these zirconium alkoxides is the increase in volatility as the alkyl group is changed from primary to secondary to tertiary. Thus:



b.p. 180° C (0·1 mm)

b.p. 160° C (0·1 mm)

b.p. 50° C (0·1 mm)

It appears here that the volatility increases with the number of atoms in the molecule, which is contrary to normal experience. It can be shown, however, that this behaviour is in fact due to the lower alkoxides being associated.

A study of the isomeric amyloxides has confirmed this. The data for titanium and zirconium amyloxides are presented in table II where M = molecular weight (determined ebullioscopically in benzene) and X = molecular complexity or degree of polymerization (i.e. M/(formula weight)).

It is evident from table II that the molecular complexity and the boiling point of a zirconium amyloxide is determined by the degree of branching of the amyl groups. The same effect is apparent, but to a lesser extent, with the amyloxides of titanium. These data are best interpreted on a stereochemical basis. Thus the straight chain alkoxides tend to polymerize by intermolecular bonding between the central atom and the oxygen atoms from alkoxide groups. This is a consequence of the well known covalency expansion which is exhibited by titanium and zirconium. Figure 2 illustrates a possible structure for a trimeric alkoxide. It is easy to see that the rotation of highly branched alkoxide groups will preclude the formation of intermolecular bonds. It is noteworthy that this shielding effect results, in the case of tertiary amyloxide groups, in the formation of a monomeric zirconium derivative which boils at a temperature three degrees below the boiling point of the corresponding monomeric titanium compound. This surprising phenomenon of the substance of higher molecular weight being the more volatile was further illustrated by the discovery that hafnium tertiary amyloxide was more volatile than the zirconium compound (table III).

TABLE III

| *Compound* | *B.p./0·1 mm* | *Mol. weight* |
|---|---|---|
| $Ti[OC(CH_3)_2C_2H_5]_4$ .. | 98 | 396·5 |
| $Zr[OC(CH_3)_2C_2H_5]_4$ .. | 95 | 439·8 |
| $Hf[OC(CH_3)_2C_2H_5]_4$ .. | 92 | 527·2 |

This interesting behaviour is of considerable theoretical interest, and further investigation [19] has shown that the phenomenon is not confined to metal alkoxides.

The stereochemical theory advanced to account for the physico-chemical properties of the alkoxides of titanium, zirconium, and hafnium would lead

TABLE II

| *Alcohol* | *Titanium alkoxide* | | | *Zirconium alkoxide* | | |
|---|---|---|---|---|---|---|
| | *B.p./mm* | *M* | *X* | *B.p./mm* | *M* | *X* |
| $CH_3.CH_2.CH_2.CH_2.OH$ .. | 175/0·8 | 565 | 1·4 | 256/0·01 | 1428 | 3·2 |
| $(CH_3)_2CH.CH_2.OH$ .. .. | 148/0·1 | 490 | 1·2 | 247/0·1 | 1462 | 3·3 |
| $(C_2H_5)(CH_3).CH.CH_2.OH$ .. | 154/0·5 | 422 | 1·1 | 238/0·1 | 1615 | 3·7 |
| $(CH_3)_3C.CH_2.OH$ .. .. | 105/0·05 | 500 | 1·3 | 188/0·2 | 1051 | 2·4 |
| $(C_2H_5)_2CH.OH$ .. .. | 112/0·05 | 399 | 1·0 | 178/0·05 | 868 | 2·0 |
| $(C_2H_5)(CH_3)CH.OH$ .. | 135/1·0 | 410 | 1·0 | 175/0·05 | 860 | 2·0 |
| $(CH_3)_2CH.CH(CH_3).OH$ .. | 131/0·5 | 415 | 1·0 | 156/0·01 | 870 | 2·0 |
| $(CH_3)_2(C_2H_5).C.OH$ .. | 98/0·1 | 405 | 1·0 | 95/0·1 | 455 | 1·0 |



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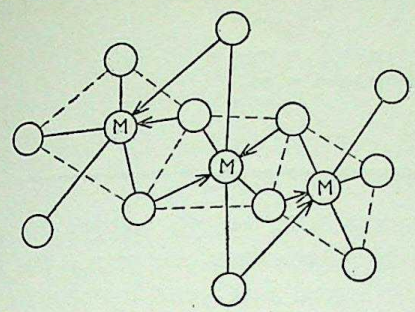


FIGURE 2

one to predict that the shielding requirements of a metal are determined by its atomic radius. Thus it appears from table II that the shielding requirement of titanium is smaller than that of zirconium, and accordingly it was expected that the requirement of thorium would exceed that of zirconium. This was indeed found to be so, because thorium gave a complex tertiary butoxide and a complex tertiary amyloxide, in contrast to the analogous monomeric compounds of titanium, zirconium, and hafnium. With thorium it was necessary to prepare the derivatives of triethyl carbinol $(C_2H_5)_3C.OH$ or methylethyl*iso*propyl carbinol in order to obtain monomeric compounds. The dependence of shielding requirement on radius of the central atom is clearly revealed in table IV, where the boiling points (° C at 0·1 mm pressure) and molecular complexities (in brackets) of a range of compounds are given.

TABLE IV

| *Central Atom* .. | *Ti* | *Zr* | *Th* |
|---|---|---|---|
| *Atomic radius* (Å) .. | 1·36 | 1·48 | 1·65 |
| Alkoxide: | | | |
| $CH_3.CH_2.O$ .. | 102(2·4) | 180(3·4) | Non volatile |
| $(CH_3)_2.CH.O$ .. | 49(1·4) | 160(3·0) | 210(3·8) |
| $(CH_3)_3.C.O$ .. | 52(1·0) | 50(1·0) | 160(3·4) |
| $(CH_3)_2(C_2H_5)C.O$ | 98(1·0) | 95(1·0) | 200(2·8) |
| $(CH_3)(C_2H_5)_2C.O$ | 128(1·0) | 128(1·0) | 148(1·8) |
| $(C_2H_5)_3C.O$ .. | 166(1·0) | 166(1·0) | 154(1·0) |

These monomeric alkoxides of thorium are more volatile than any other derivatives of this element. It seems possible that these volatile derivatives of the metals may have important industrial applications where high purity is required. Preliminary experiments show that distilled zirconium alkoxides are spectroscopically pure with respect to many common metallic impurities. Moreover, it is possible to separate hafnium from zirconium by high-efficiency fractional distillation. A new method for the separation of niobium and tantalum by means of their alkoxides is also foreshadowed. The ability to prepare the alkoxides in a high state of purity and the ease with which they can be converted to the pure oxide is of great value, particularly when the metal can be obtained by reduction of the oxide.

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# Petrology as an aid to prehistoric and medieval archaeology

F. S. WALLIS

Some two years ago we surveyed in an editorial (ENDEAVOUR, 12, 59, 1953) the rapidly increasing contributions being made to archaeology by the other sciences. In Britain, this hitherto informal co-operation was greatly strengthened last year by the formation of a special committee of the Council of British Archaeology for the purpose of co-ordinating the application of scientific research. In this article Dr F. S. Wallis describes some valuable results obtained by the application of petrology to archaeology—for example in locating ancient axe-factories and the trade routes by which their products were distributed.

In any discussion of the contributions of petrology to archaeology, the careful and pioneer investigations by the late H. H. Thomas [1], in 1923, of the source of the megalithic stones at Stonehenge will always remain a classic. After other workers had contributed what were little more than inspired guesses he showed the great value of precise investigation. His unequivocal identification, by petrological methods, of the source of the blue stones of Stonehenge as the Presely Mountains[1] in Pembrokeshire gave archaeologists a firm basis for speculation about the way in which these massive stones were transported to their present position and other problems relating to the construction and function of this famous monument.

A decade later, the group of museums and art galleries in the south-west of England set up a committee to investigate the original provenance of rocks used by Neolithic and Early Bronze Age man in making artifacts, particularly stone axes. Three reports have been issued [2], and the work, which we shall discuss in some detail later, has proved to be of such value that it is now on a national instead of a local basis.

In 1938 F. J. North [3] summarized the archaeological advantages to be gained from an exact knowledge of the petrology of materials and gave many striking examples of problems which had been elucidated by a knowledge of the rocks concerned. More recently still, W. J. Arkell [4] has written a valuable book on the origin of the materials used in the ancient buildings of Oxford, and his work has already proved an incentive to similar studies elsewhere. In particular, E. M. Jope [5] has made some brilliant architectural and economic researches and has clearly shown the fundamental value of exact petrological identification.

The inter-relationships of archaeology and geology are thus many and varied, and they are, in a broad sense, complementary to each other in the elucidation of the stirring story of the Earth and its inhabitants. It is becoming increasingly realized that archaeologists and economic historians must collaborate with petrologists in the solution of many problems.

## PETROLOGY OF PREHISTORIC SITES

In former days archaeologists ignored the underlying solid geology of the sites they investigated, though they gave some attention to the nature of gravels and other superficial deposits. Gradually this policy has changed, and no excavation is now considered to be complete unless the geology of the area has been studied and the petrological character of all finds of stone and pottery has been determined. An interesting example may be quoted from Pany-y-Saer, Anglesey [6], where C. W. Phillips found some rough, but rather remarkable, pottery in the remains of some buildings occupied between the 2nd and 4th centuries A.D. The mineral fragments in the crushed pottery were examined, and the nature of these proved conclusively that they had originated in the local Boulder Clay. It was also shown that these early people used the Upper Boulder Clay, which in Anglesey occurs in two varieties—blue or brownish-grey, and red. Thus the petrological evidence proves that the potters blended two local clays in making their final mixture—a fact of considerable social and economic importance.

In America, further work of this type has been undertaken [7] and the possibility of examining

[1] For the location of this and other places mentioned in the article see figure 1.



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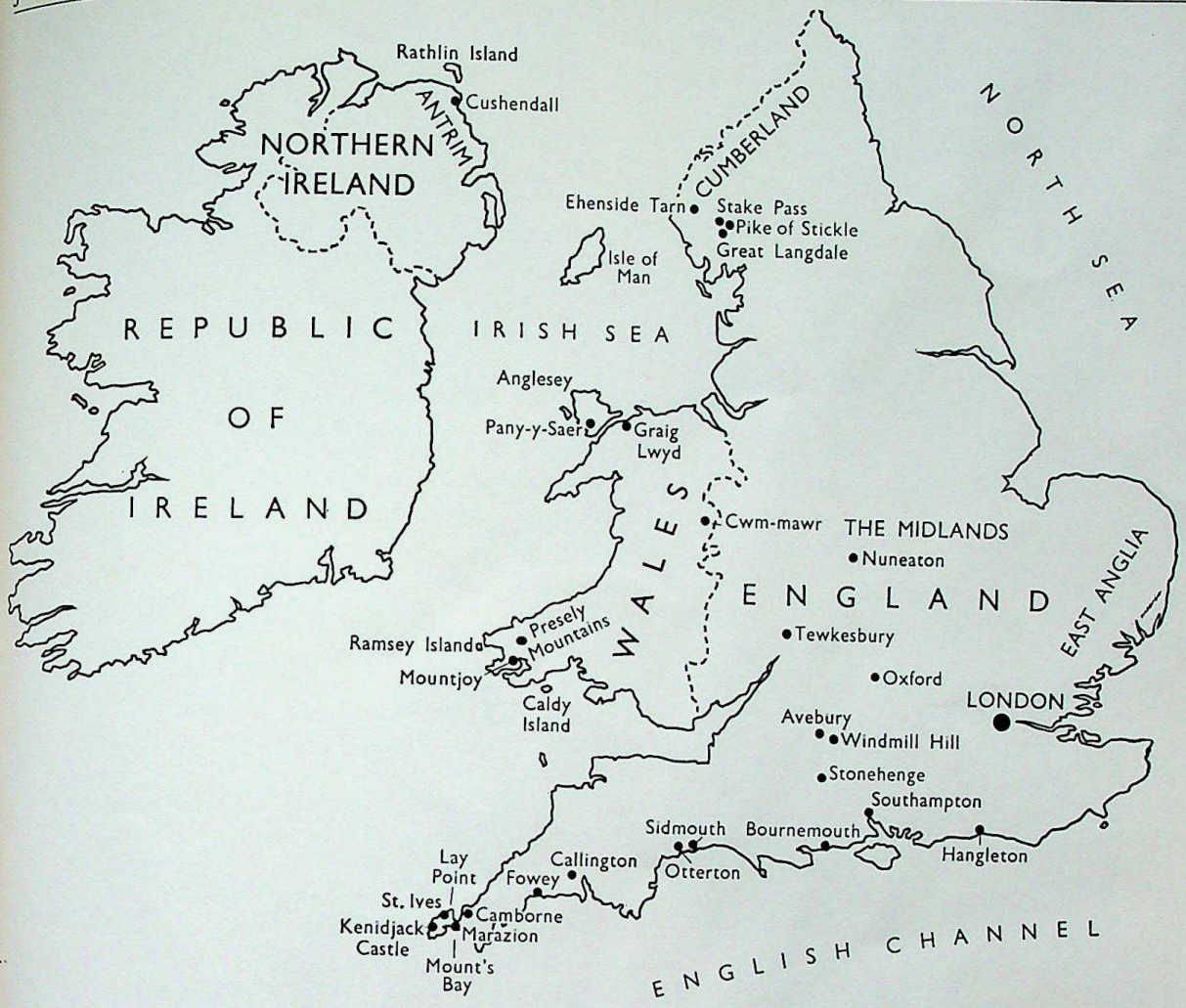


FIGURE I

thin sections of sherds of pottery, instead of isolating the heavy minerals, is being investigated. The study of thin sections has been used to obtain valuable information regarding the amount of tempering material added to the original clay base and the temperatures reached in firing.

On some archaeological sites the nature of the underlying rock has provided evidence about the water supply available to the prehistoric inhabitants. Geological evidence has also permitted interesting deductions about the original siting of dwelling places and fortifications.

### EXAMINATION OF STONE AXES

Archaeologists were originally interested only in the form and stratigraphical position of artifacts such as axes. The importance of a proper petrological examination of the numerous stone axes in public and private collections has, however, been stressed for many years past. It was urged that a knowledge of the distribution pattern of these axes would lead to a far wider and more exact understanding of the early trade routes and other factors of economic and social importance in Neolithic and Early Bronze Age times. Fortunately there is no lack of material; many such objects have been preserved in Victorian drawing-room cabinets, in the belief that they were charms or thunderbolts. A major hindrance to research, however, lay in the natural reluctance of owners to permit any damage to the specimens. Macroscopic examination, however, was rarely fruitful, for the grinding, polishing, and patination which had taken place during and after manufacture had generally obliterated any diagnostic features. It was therefore essential for the petrologist to be able to make his diagnosis by the study of a thin section under the microscope. A technique was evolved for cutting a small, plate-like piece from the stone and then grinding it to the required thickness. The



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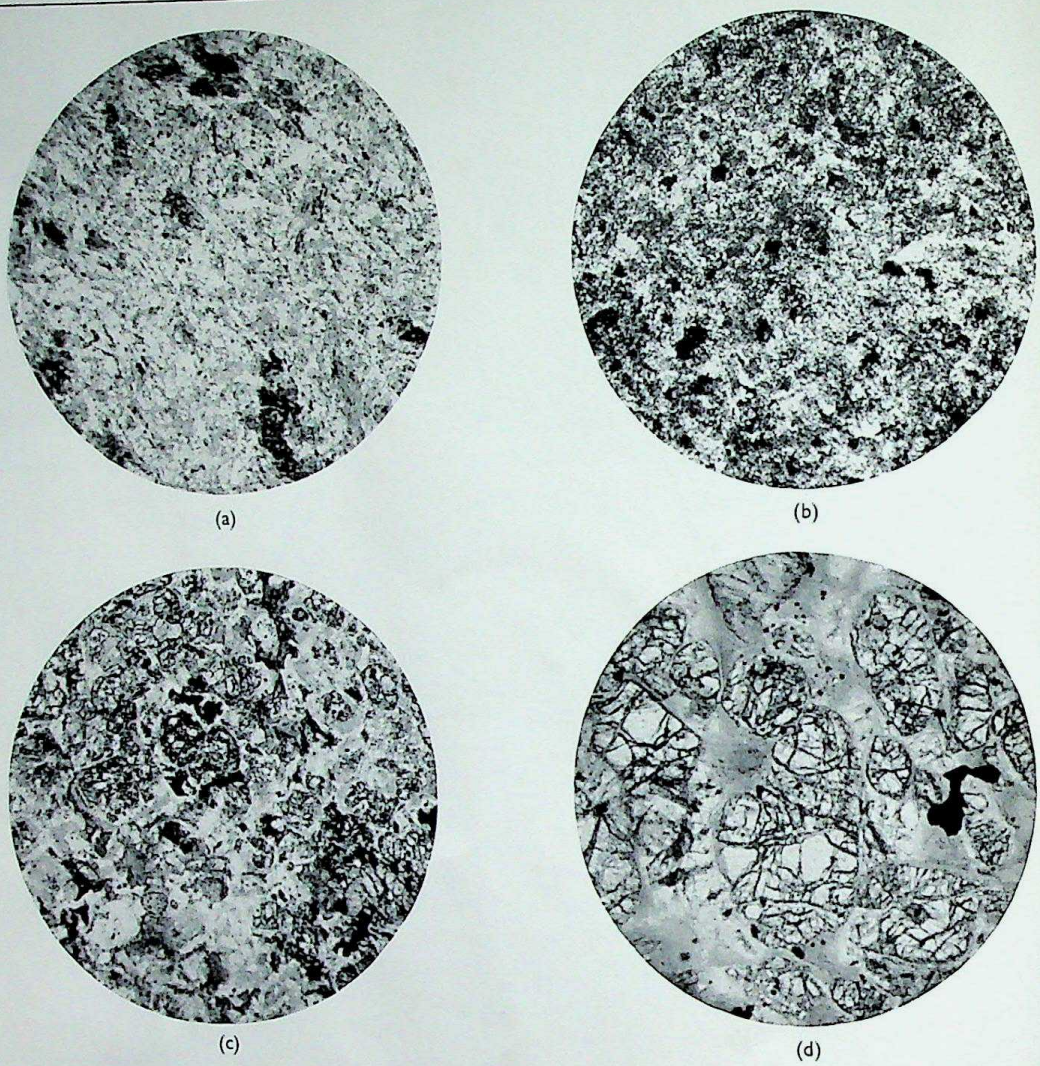


FIGURE 2 – *Photomicrographs of sections, in ordinary light, of axes, with corresponding rocks for comparison.* (a) *Group VII axe, from Avebury, Wiltshire.* (b) *Rock from Graig Lwyd.* (c) *Group XII axe, from Rollestone, Wiltshire.* (d) *Rock from Cwm-mawr, Montgomeryshire.* (*All* × 18)

(*Photographs by J. Rhodes, E. Seavill, and F. W. Shotton*)

small cavity left in the object was then filled with plaster and coloured. Thus from the collector's standpoint the stone was unaltered in appearance, and yet it had yielded the maximum petrological, and hence archaeological, information.

Many hundreds of axes have been examined in this way. Realizing the difficulty of immediately assigning an original provenance to the rocks, it was decided to allocate them to well-defined but arbitrary groups. Some seventeen such groups have already been recognized, and it is probable that the number will increase with the increase in the number of workers in this specialized but interesting field.

Groups I–IV are greenstones of varying types. Group I is a well-defined rock which weathers to a characteristic rough surface, and may be technically termed a uralitized gabbro. In this rock augite, sometimes slightly ophitic, occurs in colourless to pale-brown plates, which show a variable amount of alteration to green, fibrous hornblende. It is the presence of this secondary amphibole which accounts for the extremely tough nature of these axes. The felspars, probably albite, are much altered and are more or less riddled with needles of actinolite. Ilmenite is the chief accessory mineral. All geologists know the extreme variability of greenstones even within a



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small outcrop; the great uniformity which characterizes this group of axes shows that the prehistoric men who made them must have collected their material from a very small area. Unfortunately, the exact provenance of this rock still eludes the investigators, though a rock of very similar composition to that of the axes of Group I has been found at Gear Rock, in Mount's Bay, Cornwall. In a review of the evidence for the submergence of southern Britain, Glyn Daniel concludes that in Megalithic times the coastline was at what is now the 5-fathom line. It thus appears likely that the original source of Group I axes—and this important group comprises more than one-tenth of all the axes examined—was in Mount's Bay. The products of this factory are typologically very varied; originality in design and a breakaway from tradition were the keynotes of this relatively large industrial undertaking of Neolithic times.

Group II greenstone axes are relatively few in number, but their point of origin can be confidently assigned to a site on the coast between Lay Point and St. Ives, Cornwall. Group III is another small group, deriving from a neighbouring site at Trenow Quarry, Marazion, also in Cornwall. Here some neighbouring crags would probably give evidence of a factory if a systematic investigation were made.

On petrological evidence Group IV has been located at Balstone Down, Callington, Cornwall; the rock of which these axes are made is easily recognized in thin section as a sheared tremolite with chlorite and ilmenite. This was a relatively small factory, making chiefly normal axes, but with a tendency to specialize in large axes with thin and nearly pointed butts.

Group V is of little importance, but Group VI comprises axes which were at one time thought to be made only at Stake Pass in the Lake District, but are now known to be characteristic of the larger Great Langdale area. The rock is an epidotized tuff of intermediate or basic composition, belonging to the Ordovician (Borrowdale Volcanic series). B. Bunch and Miss C. Fell [8] have graphically described this important axe factory, the focus of which was on the scree slopes of Pike of Stickle. As at Graig Lwyd and at Tievebulliagh Hill, near Cushendall, County Antrim, which will be discussed later, it was the loose screes which attracted the early craftsman and gave him his raw material. As no polished axes have been found on the site, it is clear that only rough flaking was carried out at Great Langdale and that the finishing processes were done at one of the more permanent all-the-year-round settlements, such as Ehenside Tarn. Axes from the Pike of Stickle were traded over a wide area, for they have been found in Cumberland, the Midlands, south-west Scotland, the Isle of Man, and County Antrim, as well as the extreme south of England. As for other factories, coastal and riverine routes were favoured for distribution.

A well-known factory site on the crags of Graig Lwyd, overlooking the sea on the northern slopes of Penmaenmawr, North Wales, yielded the axes of Group VII. The rock is an augite granophyre (figure 2) and is extremely tough; it flakes well and gives good bulbs of percussion and fairly smooth conchoidal fractures. As at Great Langdale, the craftsmen concentrated on the manufacture of plain axes. The distribution pattern of these axes indicates that they were traded to Wiltshire through the Midland gap. An interesting small sub-group, VIIA, in which the rock is similar to, but not identical with, the Graig Lwyd granophyre, has recently been shown by P. R. Giot to be the exact equivalent of his Breton A group. The British examples came from Bournemouth, Southampton, Tewkesbury, and the Channel Islands, pointing to a cross-channel trade from France to ports on the south coast of England. Unfortunately, the source of the French group cannot yet be located more exactly than as being in Brittany, but it is certainly from the Armorican massif.

Groups VIII and XI may be described petrologically as silicified rhyolitic tuffs, though their exact differentiation is still a matter for discussion. Present indications rather point to the source as being outcrops of Llanvirian volcanic rocks (Ordovician) on Ramsey Island and on the mainland at a quarry near Mountjoy, Pembrokeshire, for Group VIII, according to a suggestion made by Mrs J. Morey [9]; and to the Great Langdale area for Group XI. The former suggestion has recently received support from the finding of an axe of Group VIII at Caldy Island, though this has been questioned, on typological grounds, by P. R. Ritchie [10].

Rock from the screes of Tievebulliagh Hill is the source of Group IX axes. It is a hard, mottled, bluish-black rock with darker spots, has a flinty aspect, and breaks with a splintery fracture. It is called porcellanite. It is composed of dark spinel and a light fine-grained aggregate of sillimanite and mullite. E. M. Jope [11] has



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described these factories in some detail, and has shown that in addition to a well-known one at Tievebulliagh there was another on Rathlin Island. As in the case of both Great Langdale and Graig Lwyd, no polishing appears to have been carried out at either of these two Irish factories. As no rough forms have been found outside County Antrim, it would appear likely that only polished axes were traded to Britain.

Group XII is a particularly interesting one, because it can be definitely related to a small area at Cwm-mawr, just south of Corndon Hill, Montgomeryshire [12]. This factory specialized in large perforated axe hammers—a type that is sometimes found in Group I. The rock is a picrite (figure 2) of very definite composition. The occurrence of this rock is limited in Britain, and its identity with the small outcrop at Cwm-mawr seems assured. The distribution pattern of axe-hammers found shows a preponderance in the West Midlands, with a concentration around Cwm-mawr, but it also occurs as far afield as Avebury, in Wiltshire, and Otterton, in Devon. This confident identification of rock material as coming from such a relatively small area awaits final confirmation by excavation of the factory site. From petrological and topographical considerations F. W. Shotton believes that a locality on the south-eastern side of the hill is the most likely site; this is a small, pleasant place with flat ground immediately below which would have been appropriate for the workshop.

Group XIII contains axes made from rock outcropping at Carn Meini and Cerrig Marchogian in the Presely Mountains of Pembrokeshire. This handsome and distinctive rock, with white or pinkish felspathic spots, was used for constructional purposes at Stonehenge, and is also found, as axes and axe-hammers, in such widely separated areas as County Antrim, Wales, Windmill Hill in Wiltshire, and Sidmouth in Devon. Unfortunately the exact site of the factory still eludes the archaeologists.

In recent months four other groups have been established. The essential petrological feature of Group XIV is a deep-brown pleochroic hornblende occurring in large patches, which may have good outlines, though it is frequently ophitic. There is also some augite, turbid plagioclase felspar, apatite, sphene, and pyrites. The group has been matched with a camptonite from Griff, near Nuneaton. Shotton, in addition to the determination of Group XIV, has identified a series of axes classified as Group XV; these are made of a particular type of greywacke. The rock is a chloritic, sericitic siltstone.

Groups XVI and XVII comprise two distinctive greenstones. The former is characterized by the presence of considerable quantities of hornblende occurring as patches of felted green needles, often with a parallel arrangement. It has been matched with greenstones from the Camborne area of Cornwall. Group XVII axes are made from rock in which parallel folia of clear, crystallized felspar occur in the form of a mosaic; between these are layers of brownish, fibrous hornblende, often containing knots around which the felspar folia are bent to produce augen structures. The magnetite occurs as uniform grains in the larger hornblende masses, giving the rock a characteristic appearance. Similar rocks occur near Kenidjack Castle and other places in West Cornwall.

As is to be expected from consideration of the geological structure of Britain, it was the northern and western districts which supplied the tough igneous rocks used for the manufacture of these early implements; in the eastern and southern areas flint was mainly used, and the mines there bear witness to the source. It is interesting to note that in a recent examination of some stone axes from East Anglia examples of only the more successful groups—namely Graig Lwyd, Great Langdale, and Group I—were encountered. These were the more popular types, and in consequence were traded to distant parts of the country.

From this intensive research, now being carried on in several parts of Britain, there is slowly emerging a picture of the trade routes involved in the economic dispersal of early tools and weapons. The distribution pattern clearly indicates the great importance of coastal and riverine routes, though the products of the Graig Lwyd factory were mainly traded overland through the Midland gap.

The importance of Avebury in Neolithic times is clearly revealed by this new line of research, for it is shown to have been the centre of the axe trade. Products of all the important factories, and even of most of the lesser ones, are represented there, and Niedermendig lava from the Rhine has also been recorded. This is an impressive fact, and it has been suggested that a possible explanation is to be found in some form of spiritual rather than material exchange, for it is difficult to believe that there can have been any considerable bartering at Avebury with products of the local chalk and flint.



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PETROLOGY AND MEDIEVAL ARCHAEOLOGY

The growing value of petrology to the prehistoric archaeologist is thus evident, but it is encouraging to see that scholars interested in later periods also recognize that an exact determination of the nature of stone used can assist the elucidation of the complete story. Thus the patient determination of the several types of stone used in Oxford, by W. J. Arkell [4], has made an important contribution to the study of the regional building characteristics, now rapidly disappearing. The source of the many types of stone used in Oxford has been traced back to the individual quarries from the Middle Ages to the present day. It is academically a valuable survey and has also a practical value, for it has long been established that the most aesthetically satisfactory repairs and restorations of buildings are those in which the original type of stone is used rather than those now fashionable, however sound and durable these may be.

Similar studies are being made elsewhere. For example, granite obtained from the five outcrops in the south-west of England was used in both Cornish and Devon churches in rebuilding which took place in the fifteenth and sixteenth centuries, and the distribution pattern of the easily recognized Purbeck marble is slowly becoming clear.

Recently, E. M. Jope and G. C. Dunning [13] have carried out a survey of the use of blue slate for roofing in medieval England. This is based on petrological evidence linked with documentary records. The result, though not final, is illuminating, and indicates that, with the exception of a Belgian slate found in the deserted medieval village of Hangleton, the roofing slates found in many medieval sites in southern England are from the Devonian formation. Not only has it been possible to establish the sites of the old quarries, but the transport routes on the southern coast, for example from Fowey to Southampton, have been worked out. The routes of the blue slates from other localities in the western parts of Britain, including Pembrokeshire and North Wales, have also been traced; these too indicate a vigorous coastal trade. The nature of the export trade to Ireland, France, and the Netherlands has been established in broad outline, emphasizing the fruitful results that may be obtained by collaboration between the economic historian and the petrologist.

In April 1954 an informal conference of archaeologists and scientists was held in London to discuss how they could best help each other. Later in the year this led to the formation of a Scientific Research Committee of the Council of British Archaeology, set up for the purposes of co-ordinating and advising on the applications of scientific research to archaeology. Collaboration between the petrologist and the archaeologist, with particular reference to the study of stone axes, is one of the major considerations of this committee.

In preparing this summary I have drawn freely on the work of colleagues, and I should like to take this opportunity of acknowledging the consistent co-operation of Mr E. D. Evens, Mr E. M. Jope, Mrs J. Morey, Professor F. W. Shotton, and Dr J. F. S. Stone.

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# The permanent magnetization of rocks

S. K. RUNCORN

There is strong evidence, here discussed, that the direction of magnetization of rocks perpetuates that of the Earth's field at the time of their formation. On this assumption it is possible, by examining rocks of known age, to discover the variations which have taken place in the direction of the Earth's field. Of outstanding interest is the considerable body of evidence that the geomagnetic field has in the past undergone repeated reversals.

The fossilized remains of once living organisms indicate the conditions of life obtaining at the time of their formation. Recently it has been found that there exists another, equally widespread, fossil—but of a physical rather than biological nature. It has been shown that many sedimentary strata, or series of lava flows or other igneous rocks, are magnetized in various directions, but that in general the directions are uniform within a given geological epoch. These magnetic fossils can be of considerable value.

The only common minerals capable of becoming permanently magnetized are the iron oxides; chief among these are the titanomagnetites and haematite. The former are a series of solid solutions of magnetite ($Fe_3O_4$) and ulvospinel ($Fe_2TiO_4$). In this series the Curie point (above which ferromagnetism disappears) is lowered, and the saturation magnetization decreases, as the proportion of titanium increases; the Curie point for pure magnetite is 575° C, but it is 220° C if the molecular proportion of ulvospinel is 50 per cent. Haematite ($\alpha$-$Fe_2O_3$) has a Curie point of 675° C, and a saturation magnetization of about 0·5 e.m.u./g, compared with 92 e.m.u./g for pure magnetite. Haematite forms solid solutions with ilmenite ($FeTiO_3$), and these are ferromagnetic. Maghemite ($\gamma$-$Fe_2O_3$) has a cubic lattice similar to that of magnetite and is strongly ferromagnetic, but as it is unstable at temperatures above approximately 300° C it is likely to have resulted in the main from the oxidation of magnetite during the weathering of rocks.

These iron oxides are not easy to study by the usual petrological techniques, as they are opaque even in thin sections: consequently their wide range of composition was not appreciated until comparatively recently. A further complication is that structures occur in which laminae of one component have separated out from solid solutions; these may form intergrowths, of two different compositions, ranging in thickness from a few microns upwards. With the metallurgical microscope these intergrowths may be seen on the polished surface of the ore grains, especially if the latter are etched. However, the structure and texture of iron oxide minerals, which form only a few per cent of the material studied, are of considerable importance to the magneticians interested in the remanent magnetization of the rocks, so that study of detail may be essential.

There seem to be two ways in which such minerals can become magnetized. If an unmagnetized assemblage of grains, above the Curie point, is cooled down in a magnetic field, even one as weak as that of the earth (0·5 gauss), the grains can acquire a magnetization corresponding to a considerable fraction of their saturation magnetization. This thermo-remanent magnetization (T.R.M.) arises because just below the Curie point the coercive force is only a fraction of a gauss. Provided the grain size is neither too large nor too small, however, the coercive force at ordinary temperatures is large, 50 gauss for pure magnetite and several thousand gauss for haematite. T.R.M., when once acquired by a rock, is stable, because rocks are not generally subjected to strong magnetic fields nor to high temperatures. The second way in which such grains may become magnetized depends upon the fact that at ordinary temperatures some iron oxides may acquire appreciable isothermal remanent magnetization (I.R.M.) by prolonged influence of the geomagnetic field. E. Thellier and F. Rimbert [1] have shown that I.R.M. is more easily destroyed by alternating-current demagnetization than is T.R.M.

If a rock is magnetized in the same direction as the present geomagnetic field, it may be either because the field was in the same direction at the time of the rock's formation, or because the rock has acquired appreciable I.R.M. over the last few



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hundred thousand years. In the latter case the rock is regarded as magnetically unstable, and it is distinct from those which have successfully 'fossilized' the geomagnetic field existing at the time of their formation. There is at present no infallible test for instability, but it is prudent to exclude rocks with low coercive force or low Curie points and those which are lithologically similar to rocks known to be unstable.

Proof that T.R.M. is responsible for the natural magnetization found in a rock is in principle not difficult. The natural magnetization should decay, as the rock is heated, in exactly the same way as does the T.R.M. given to another sample of the same rock by cooling it from above the Curie point in the geomagnetic field. This is an important way of investigating which of the iron oxides are present, because the decay of magnetization is sufficiently rapid just below the Curie point to allow this temperature to be determined quite accurately. It is unfortunate, however, that not only may a naturally occurring rock have lost some of its magnetism through ageing, but that the geomagnetic field may be of a very different strength today from that obtaining at the time of formation of the rock. Consequently the heating experiments may give only qualitative evidence to support the presumption of the thermo-remanent origin of the magnetization. The problem may indeed be more considerable than this; on heating, changes may occur in the opaque minerals which alter their composition and Curie points. In this case we shall get no evidence whatever of the nature of the initial process of magnetization.

It seems, however, that intense and stable T.R.M. probably accounts for the natural magnetization of all the rocks which are of interest in the present context. The rocks of the Earth's crust have been formed either directly by the cooling of molten magma to form igneous rocks, or by the deposition, and subsequent consolidation and cementation, of eroded fragments of other rocks, forming sediments which are usually well stratified. Both igneous and sedimentary rocks may—by deep burial under pressure and at high temperature, or by chemical action—be appreciably changed. The magnetization of such metamorphic rocks has not so far been much investigated, as their history is clearly complex. Going back in geological time, one would naturally expect to find more strata in which the original magnetism has been lost and which have become wholly or partially remagnetized along new directions.

### MAGNETIZATION OF IGNEOUS ROCKS

In the present context the most interesting examples of igneous rocks are perhaps the lavas, which often emerge from fissures in the ground. If basaltic, and therefore of low viscosity, they can flow over large distances, perhaps tens of miles, and form layers of remarkably uniform thickness, often some dozens of feet thick. In some places successive eruptions of lava dominate the landscape, as in the Columbia River region in the north-west of the United States, and in Iceland. In such a region one has a clearly defined series of rocks which not only must have acquired T.R.M. but form a chronological sequence, the intervals between eruptions ranging from a few years to a few tens of thousands of years.

In a series of measurements of the Tertiary basalts in Iceland, J. Hospers [2], found that some groups of lavas are magnetized in the present direction of the geomagnetic field and other groups in exactly the opposite direction. This normal and reverse magnetization has now been found to be characteristic of the Columbia River basalts (C. D. Campbell and S. K. Runcorn [3]) and of those of the Central Massif of France (A. Roche [4]), all of which are of Tertiary age.

Isolated examples of reversed magnetization had previously been noted. In particular, it was known from magnetic surveys that many dykes—walls of solidified magma which were once fissures through which molten lava had issued—consisted of reversely magnetized material. Figure 2 shows an example of a dyke cutting through horizontal lava flows in the Columbia River basalts of the north-west United States. H. Gelletich [5] demonstrated that the great Pilansberg system of dykes in South Africa was reversely magnetized, and J. M. Bruckshaw and E. I. Robertson [6] showed that the magnetization of the tholeiite dykes of northern England also was reversed.

The interpretation of these results has led to much discussion. Those who have examined the rocks in question see no reason to doubt that, in general, reversed magnetization arises from a reversed geomagnetic field existing at the time of cooling of the lava. The fact that reversals occur a number of times in the series of lavas mentioned above is taken to indicate that reversals of the geomagnetic field may take place at irregular intervals, of the order of a few hundred thousand to a few million years.

P. M. S. Blackett [7] has recently called this explanation of reversed magnetization in rocks the 'obvious' one. On the other hand, as recently as


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1951 L. Néel [8] could preface a paper, which attempted to show how reversed magnetism could arise from anomalous properties of the iron oxide minerals, with the statement that the theory of the geomagnetic field precluded reversals. It is only within the last few years that the idea of reversals of the main geomagnetic field has come to be seriously entertained by physicists as a likely explanation of reversed magnetization. The growth of our concepts of the physical processes which go on in the Earth's interior has had much to do with this growth of our ideas about the geomagnetic field. These concepts are twofold. The Earth possesses a liquid core some 3400 km in radius; the comparatively rapid changes in the geomagnetic field, indicated by the variation of the magnetic declination in Europe during the last five hundred years, point to fluid motions in this core, probably the result of thermal instability. The gyroscopic effect of the rotation of the Earth is a dominant factor in the symmetry of these motions, and results in the coincidence of the magnetic axis of the Earth with its axis of rotation when the effects of the secular variation are averaged over a few thousand years. Without going deeply into the theory of the main geomagnetic field, it is evident that on this basis we can attach no fundamental significance to its polarity. Indeed, all attempts to produce a satisfactory explanation of the field make it evident that the external dipole field is secondary to, and much smaller than, the so-called toroidal field, the lines of force of which remain within the electrically conducting interior of the Earth.

Nevertheless, a number of attempts have been made to explain the anomalous magnetization in terms of unusual properties of the iron oxide minerals rather than by reversal of the geomagnetic field. Néel [8] has shown that four such possibilities exist. Two processes apply to igneous rocks, and relate to the method by which magnetization is acquired on cooling. If the iron oxide minerals consist of two separate ferromagnetic phases, as in the intergrowths previously discussed, and if a phase A has a higher Curie point than phase B, it is possible that when its Curie point is reached B will be cooling in a field reversed by the 'return field' of the already magnetized material A. If A has a smaller temperature coefficient of magnetization than B, it is possible for the reversed magnetization of B to be predominant at ordinary temperatures. T. Nagata [9] has apparently found two volcanic rocks which behave in this way, but careful examination of the basalts referred to above has revealed no such properties in them. The second process suggested by Néel depends on the imperfect antiferromagnetism of the iron oxides. Owing to quantum mechanical exchange forces, the magnetic moments of the atoms in a domain in iron are aligned in parallel and in ferrous oxide in antiparallel. Thus the latter material does not have ferromagnetic properties and cannot be permanently magnetized. The ferromagnetism of such a material as magnetite is due to an imperfect antiparallel arrangement of elementary moments, those of one sign outweighing those of the other. Néel shows that in some cases this situation may be reversed by change of temperature, and a lithium ferrite has been synthesized that has this property, but no naturally occurring rock is known to possess it.

The other processes which Néel suggested apply both to lavas and sediments, but have not been experimentally demonstrated. These suppose that the two processes described above may occur at ordinary temperatures as a consequence of chemical or structural changes in the iron oxide minerals, occurring perhaps only over millions of years.

It is possible that such phenomena must be taken into account in the interpretation of reversed magnetization. Néel's processes seem, however, to depend on coincidences too improbable to allow their very widespread occurrence in nature. Moreover, no differences have been found in average magnetic properties between reversed and normal specimens. Nor do the two processes described above which have actually been observed account for reversed magnetizations in sediments which have been investigated in the last few years.

### MAGNETIZATION OF SEDIMENTS

To extend the palaeomagnetic record, particularly for pre-Tertiary times, it is necessary to examine the remanent magnetization of sediments as well as of lava flows. Work of this kind has been going on for some twenty years, but it is only recently that interesting and significant results have been obtained. In general, the intensity of magnetization of lava specimens lies between $10^{-2}$ and $10^{-4}$ gauss, while that of sediments is less than $10^{-4}$ gauss. The smaller proportion of iron oxides in sediments does not alone account for this difference, which must therefore be due to the iron oxide grains having a smaller intensity of magnetization than those in lavas, or to a much greater scatter of the directions of magnetization. The iron oxide grains must have originated in an



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(a)

(b)

(c)

(d)

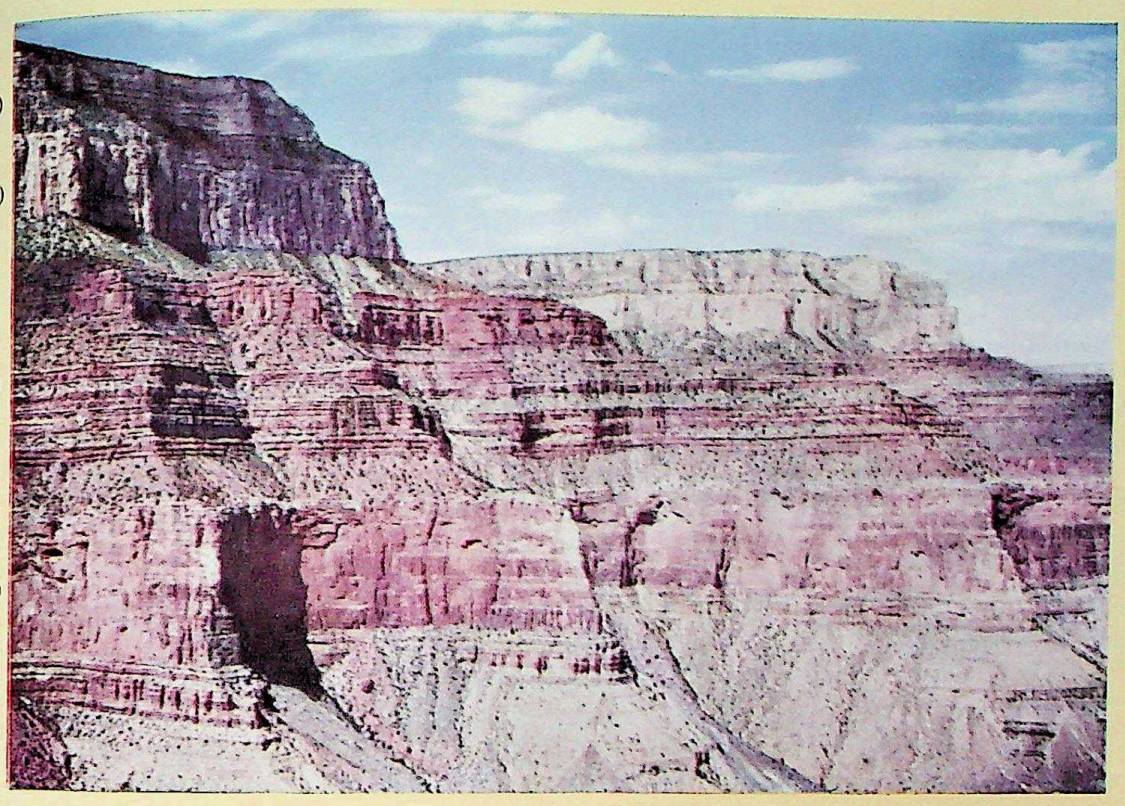

FIGURE 1 (*above*) – *Red Sandstones and shales of the Supai (Permian) formation of the Grand Canyon, Arizona.* (a) *Kaibab limestone;* (b) *Coconino sandstone;* (c) *Supai formation (shales and sandstones);* (d) *Redwall limestone.*

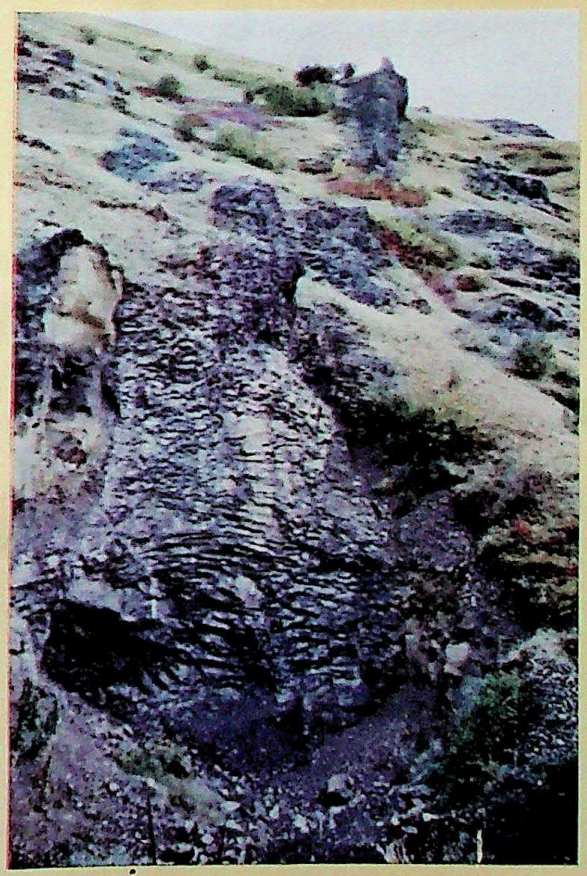

FIGURE 2 (*right*) – *Dyke cutting through horizontal lava flows in the Columbia River basalts, near Redmond, Oregon.*

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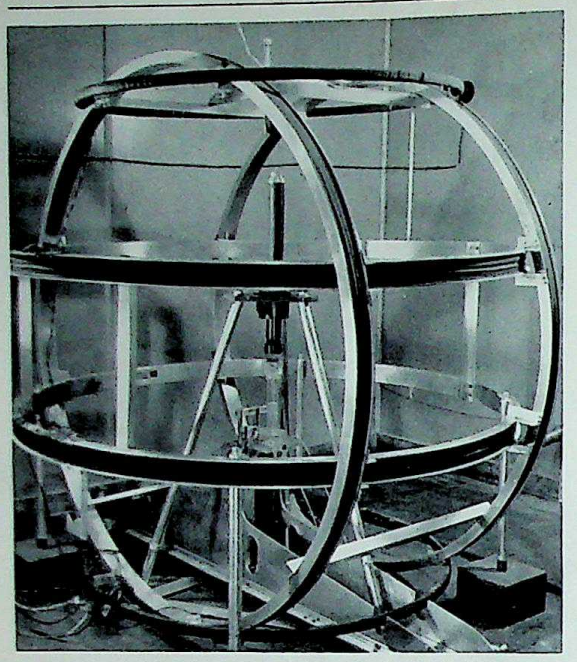

FIGURE 3 – *Astatic magnetometer, showing Helmholtz coils, for removing the horizontal and vertical components of the geomagnetic field, the magnetometer, and specimen holder.*

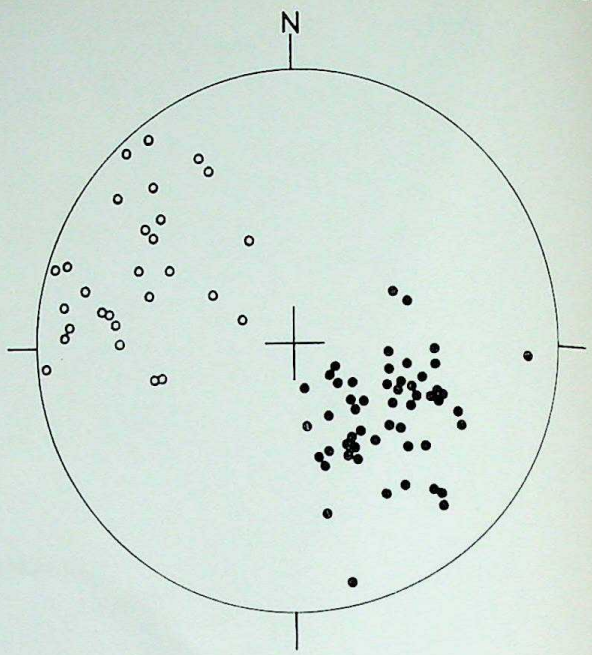


FIGURE 4 – *Directions of magnetization of Torridonian sandstones. Open circles = upward directions. Closed circles = downward directions.*

igneous rock, in which they presumably had T.R.M. We might expect the process of erosion, transport, and deposition to which the grains would be subjected, and possible chemical changes also, to reduce this magnetization very considerably. At any rate, it is significant that when a sediment is heated beyond the Curie point and then cooled in the geomagnetic field, it can receive a magnetization a thousand times its natural one. We may tentatively believe that during the deposition of the sediment in reasonably still water the magnetized iron oxide grains rotated under the influence of the ambient geomagnetic field, giving the sediment a weak magnetization in the direction of the field.

Figure 3 shows the astatic magnetometer used at Cambridge for the measurement of the magnetization of sediments: it is a development of the astatic magnetometer made by P. M. S. Blackett [10]. The specimen, in the form of a short cylinder, is raised underneath the lower magnet of the astatic pair and the deflection is noted. The procedure is repeated with the cylinder rotated through successive small angular increments. In this way one can measure the component of the magnetization in different directions in the plane of the disc. If the disc is cut out of the rock specimen in such a way that its axis corresponds to what was the vertical when the sediment was laid down, these measurements give the palaeomagnetic declination. A more complicated procedure enables the inclination to be measured also.

The first sedimentary series to be examined in Britain were rocks from the Torridonian sandstones of north-west Scotland; these are of late pre-Cambrian age. Sixty-three localities, spread over seventy miles of the coast, were sampled by E. Irving, of the Department of Geodesy and Geophysics, Cambridge University, to provide material for an examination of a reasonable fraction of the succession, which is 3000 m thick. The reversals of magnetization so characteristic of the Tertiary lava flows are found also in this series of rocks. Reversals occur every 30–600 m in the succession. What this means in terms of geological time is, of course, impossible to determine, but a mean rate of deposition of 1 cm per year is probably of the right order of magnitude. Ten localities have been found in which directions of magnetization occur which are widely different from those in fifty-three other localities. These variant directions of magnetization are thought to represent periods during which the geomagnetic field was in the process of reversal. During such a period of change one would not expect the field at the Earth's surface to be a simple dipole: one would expect a much more complicated field. Consequently the presence of these oblique zones



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gives support for the reality of reversals of the geomagnetic field. The magnetization of these rocks differs from those of the Tertiary age in that the directions are at a large angle to those of the present field; this is shown in the accompanying stereogram (figure 4).

### FIELD TESTS OF MAGNETIC STABILITY

The evidence that the direction of magnetization of sediments is indicative of the direction of the geomagnetic field at the time of deposition is not very direct. It is possible, by making use of some ideas put forward by J. W. Graham [11], to show that the magnetization has not changed since early in the history of the rocks. Two tests of the permanence of magnetization acquired at the formation of a rock are afforded by nature. First, in folding and other earth movements, strata may be so moved that contemporaneous layers lie for much of geological history with their bedding planes at very different angles in different outcrops. If there is any tendency for such rocks to be magnetically unstable, even over periods far too long to be observable in the laboratory, they will become magnetized partially or wholly in the direction of a magnetic field imposed later. In that case the directions of remanent magnetization found in the rocks today will be more nearly parallel than one would expect if their magnetization had been assumed on formation. The second field test of stability consists in examining the remanent magnetization of conglomerate pebbles, derived from the rock strata through erosion. In the formation of the conglomerate bed the pebbles would obviously be deposited without reference to their magnetization, i.e. the directions of magnetization would be random. Unless the material from which the pebbles were formed is magnetically unstable, this randomness will persist.

The above tests do not exclude the possibility that the original magnetization has assumed some preferred direction within the rocks. It might be, for example, that iron oxide particles of a particular shape are preferentially orientated by hydrodynamic forces and by gravity during deposition. It is possible that such particles retain their magnetization better than those of irregular shape, in which case the direction of magnetization in the rock would gradually change. If such effects do occur they are probably small, but corrections may have to be made for them. Perhaps the most cogent argument against them is the uniformity of magnetization found over great distances in such a series as the Torridonian. It is even more convincing when igneous rocks and sediments of the same age can be compared.

### SURVEY OF THE MAGNETIZATION OF THE GEOLOGICAL COLUMN

Much progress has been made in finding the directions of magnetization characteristic of a considerable number of geological epochs. K. M. Creer, of the Department of Geodesy and Geophysics, Cambridge University, has selected Red Sandstones (of the type that Irving found to be stable in the Torridonian) from a number of geological epochs and found them to be consistently magnetized within each epoch. These directions are given in table I, and are taken from a brief paper by Creer, Irving, and Runcorn [12]. Also, an extensive survey of the New Red Sandstone of Triassic age has been made by J. A. Clegg, M. Almond, and P. H. S. Stubbs [13], who show that these rocks are consistently magnetized along a NW–SE axis. Approximately equal numbers of reversed and normal magnetizations were found.

Well-bedded fine-grained Red Sandstones of the type which have been extensively used in this work occur in many geological formations and are well exposed at many levels in the Grand Canyon, Arizona (figure 1) where work is being undertaken at present.

### POLAR WANDERING

It is clear that some unifying hypothesis is required to give significance to these varying palaeomagnetic declinations and inclinations. If one considers the situation that obtained in Tertiary times, one sees that in spite of frequent reversals the direction of the magnetization of the lavas remains close to that of an axial dipole. J. Hospers [14] has considered this point carefully. Modern palaeontology is quite definite that no appreciable change in the position of the pole could have occurred in Tertiary times. Thus in order to explain the pre-Tertiary results it seems reasonable to suppose that the axis of rotation and the magnetic axis have always coincided, an assumption which has already been justified theoretically. It is therefore necessary to assume that there has been a movement of the land relative to the poles. This possibility has long been seriously considered by geologists in order to explain certain climatological and palaeontological difficulties.

It should be made clear that there are two possibilities to distinguish between. Continental drift envisages the separation of the continents, while



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TABLE I. *Direction of magnetization of Red Sandstones*

| *Geological period* | *Approximate age (million years)* | *Average directions* | | *Corresponding position of geomagnetic poles* |
|---|---|---|---|---|
| | | *Declination* | *Inclination* | |
| PRE-CAMBRIAN | 600 | N 56° W | − 38 | N: Mid-Pacific 130° W, 0° N |
| (Torridonian) | — | S 69° E | + 19 | S: Near Ethiopia 50° E, 0° N |
| PALAEOZOIC Cambrian .. | 450 | S 11° W | + 41 | N: Marshall Islands 170° E, 15° N S: South Atlantic 10° W, 15° S |
| Silurian .. | 350 | S 25° W | − 16 | N: North Honshu, Japan 140° E, 40° N S: South Atlantic 40° W, 40° S |
| Devonian .. | 300 | N 34° E | + 2 | N: Near Kamchatka 155° E, 45° N |
| | | S 18° W | − 2 | S: South Atlantic 25° W, 45° S |
| Permian .. | 200 | S 19° W | − 9 | N: Near Kamchatka 155° E, 45° N S: South Atlantic 25° W, 45° S |
| MESOZOIC Triassic .. | 180 | N 26° E | + 28 | N: Near Kamchatka 155° E, 48° N |
| | | S 34° W | − 28 | S: South Atlantic 25° W, 48° S |
| TERTIARY Eocene .. | 60 | S 14° W | − 60 | N: New Siberian Islands 133° E, 76° N S: Antarctica 47° W, 76° S |

polar wandering assumes no relative motion of the land masses, but only a shift of the Earth relative to its axis of rotation in space. The modern theory of continental drift originated with Wegener, who supposed that in late Mesozoic times the continents drifted apart, having previously been grouped together in two masses called Laurasia and Gondwanaland. The theory is supposed to explain the following curious facts:

1. The similarity of the west coast of Africa and the east coast of South America.

2. The supposed similarities of fauna and flora in those parts of (*a*) North America and Europe and (*b*) South America, Africa, India, and Australia, which would have been joined together as the original two continental masses of Laurasia and Gondwanaland.

3. The glaciations of Permian and Carboniferous times, which were widespread throughout Gondwanaland.

The theory of continental drift has had a great fascination for certain scientists: no symposium on the subject fails to attract great attention. It is, however, based on no unambiguous geological evidence, and the geophysical case against it (H. Jeffreys [15]) has never been answered. Its plausibility arises principally from the attractive conception of the continents as rafts floating on a basaltic substratum, like icebergs floating in the sea. This analogy has, however, one fatal flaw: the strength of the continental rafts is less than that of the basaltic substratum under the oceans. The wide popularity of the theory of continental drift seems to be due to a feeling that it must somehow be simpler to move the continents than to move the Earth relative to its axis of rotation in space.

Perhaps the most unambiguous geological evidence relating to earlier positions of the land masses is that deduced from former climates. Yet in discussing this with reference to the above theories, geologists time and time again refuse to admit the possibility of polar wandering. The best-known climatic zones are those of the Carboniferous. In the latter half of last century beds of tillite—the boulder clay characteristic of glaciations—were found in South Australia, India, South Africa, and South America. That of Australia is of Permian age, those in India and South Africa are Permo-Carboniferous, and the South American glaciation is early Carboniferous. They are not contemporaneous glaciations—perhaps many tens of millions of years separate them. Yet it is often argued that polar wandering cannot explain this widespread glaciation and that we must invoke the idea that these four continents were at that time close together. In the same geological epoch the great coal forests were flourishing in North America, Europe, Russia, and China. Beds of laterite and bauxite, which now form only in the humid tropics, are also found in the Upper Carboniferous in these places. It is, of course, possible that these changes of climate may



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have affected the Earth as a whole and may have resulted from fluctuations of solar radiation. The establishment of contemporaneity of geological age is perhaps not good enough absolutely to exclude this possibility.

It is of interest to examine the results of measurements of the magnetization of Carboniferous rocks. J. C. Belshé, of the Department of Geodesy and Geophysics, Cambridge University, has recently shown that the Carboniferous strata of Derbyshire and Yorkshire are magnetized with a low angle of dip, as if they had been magnetized in a field appropriate to the equatorial belt. Similarly D. I. Gough [16], of the Bernard Price Institute for Geophysical Research, University of the Witwatersrand, has recently shown that the Pilansberg dykes near Johannesburg are magnetized nearly vertically, as if the north magnetic pole had been in Abyssinia when they were formed. Though the age of these dykes is rather doubtful, they are earlier than late Carboniferous but probably later then Ordovician.

It will be possible in the next few years to see whether the hypothesis of polar wandering provides a satisfactory general explanation of the pre-Tertiary palaeomagnetic directions, by thoroughly comparing rocks from different continents. The present writer believes that this, and not continental drift, as Blackett [7] seems to suggest, will prove to be the key to the magnetism of rocks. We may not have long to wait before the matter is settled, but in any event a new and exciting chapter in the Earth's history seems to be on the verge of disclosure.

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# Book reviews

### HISTORICAL SCIENTIFIC BOOKS

Scientific Books, Libraries and Collectors, *by John L. Thornton and R. I. J. Tully. Pp. X + 288. The Library Association, London.* 1954. 24*s. net.*

This work is a companion volume to 'Medical books, libraries and collectors,' published in 1949. The principal part of the work consists of an account of the more important scientific books up to and including those of the nineteenth centuries. These are classified first by date, then by subject and author. The book is not a formal bibliography, but gives a readable account of the authors and their books. It is obviously very far from exhaustive, and every historian of science will no doubt think that his own subject has been inadequately treated: the reviewer, for example, finds the account of alchemy very slight; it is surprising, too, to find that the magnificent 'Pirotechnia' of Biringuccio and Lazarus Ercker's work on assaying are missing.

The authors are, however, too modest in stating that the professional historian of science will find in their pages little that is new: such a historian, outside his special subject, will find the book of great use, and it will receive a permanent place on the reviewer's table. In addition to the general survey of scientific books there is a good account of scientific bibliographies, and also chapters upon scientific societies and libraries, all valuable. There is some inconsistency in the transcription of names, which are often half Latin and half Greek. Thus we have both Timaeus and Timaeos but not Timaios; Albertus Magnus sometimes appears, rather surprisingly in an English book, as Albert der Grosse. There are also a good many misprints, which is unfortunate in a book from which much will be copied.

F. SHERWOOD TAYLOR

### CHAUCERIAN ASTRONOMY

The Equatorie of the Planetis, a manuscript treatise ascribed to Chaucer; *edited by D. J. Price, with a linguistic analysis by R. M. Wilson. Pp. xvi + 214. Cambridge University Press, London.* 1955. 52*s.* 6*d. net.*

Though the history of science is still far too neglected a subject, the historian can have not more than a faint hope of



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unearthing an overlooked scientific treatise of major importance. This good fortune has, however, fallen to the lot of Dr Price—and deservedly so, for his careful scholarship had already won recognition. When examining manuscripts in the library of Peterhouse, Cambridge, he observed that in an English text on an astronomical subject the date 1392 frequently occurred, and at first surmised that it might be a missing part of Chaucer's 'Treatise on the Astrolabe,' written in 1391. Closer investigation proved that it was in fact a description of an equatorium or planetary calculator, of which only one medieval example appears to have survived, namely that at Merton College, Oxford.

This discovery was exciting enough in itself, but the excitement grew when Dr Price found the signature 'Chaucer' in a marginal note on one of the folios of the manuscript. There was at least the possibility that the treatise was not only by Chaucer but in his holograph, and this possibility is discussed at length in one chapter of the book. While not claiming to have definitely proved the point, Dr Price adduces sufficient evidence to make it highly probable that in 'The Equatorie of the Planetis' we have an original work by Chaucer written by his own hand: the find is therefore not only of scientific interest but of very considerable literary value.

In this edition the text is reproduced in facsimile and is accompanied by a transliteration and a translation into modern English. The critical apparatus includes a history of the equatorium and an account of medieval astronomical theories. There is a glossary of unfamiliar terms, and Mr R. M. Wilson provides a useful linguistic analysis. As usual, the Cambridge University Press has done the work of production extremely well, in a style befitting the exceptionally interesting subject. To use a phrase now outmoded, this is a book 'for every gentleman's library.'

E. J. HOLMYARD

### PLANETARY ASTRONOMY

Guide to the Planets, *by Patrick Moore. Pp.* 222. *Eyre and Spottiswoode (Publishers) Limited, London.* 1955. 21*s. net.*

The present state of knowledge about the planets of the solar system is adequately described in this volume. This knowledge is based upon visual, photographic, and spectroscopic observations, combined with theoretical considerations. The subjects of space travel, voyages to the planets, and the establishment of a Martian base are inevitably brought in. The author is a well-known amateur observer, and some of the views put forward are his own personal opinions and not universally accepted. He states, for instance, that the theory that the lunar craters were made by meteors is 'quite untenable,' and that no practical lunar observers have any use for it now. That is certainly not so. The importance of some of the observations of lunar features made by amateur observers is somewhat shaken by the very considerable divergences between drawings of the same features—made usually from observations with telescopes of very moderate resolution—and the interpretation of these observations. Some of the lunar observers appear, moreover, to be under the impression that one theory and one theory only should account for every type of lunar formation.

The volume will form a useful guide for the planetary observer, who should use his own judgment, however, in weighing the evidence for different points of view. Most of the recent work has been well summarized. The book is illustrated with some good photographs and with some excellent coloured drawings by L. F. Ball.

H. SPENCER JONES

### METEOR ASTRONOMY

Meteor Astronomy, *by A. C. B. Lovell. Pp. xiv* + 463. *Oxford University Press, London.* 1954. 60*s. net.*

Since the 1930's our knowledge of meteors has been revolutionized by modern photographic methods and the spectacular radio-echo techniques. In this comprehensive survey the author, himself a leader in the field of radio-astronomy, places the remarkable period of transition and development in its true perspective in relation to the long patient work of the past. In this way Professor Lovell has forged a vital link in the technical literature of meteors. Whether one is seeking information about technique, a critical and lucid exposition of the work of individual observers, or an objective account of the data of observation and the present state of meteor theory, this will be the book to turn to now and for many years to come.

The thoroughness and detail of the treatment have necessitated the complete exclusion of any discussion of meteorites or the physics of meteors; but we look forward to the adumbrated companion volume on these topics which, while not strictly part of meteor astronomy, are part of that 'question mark' in the human mind that first prompted the scientific observation of 'shooting stars.'

P. J. TREANOR

### PHYSICAL CALCULATIONS

Advanced Level Examples in Physics, *by R. V. Johns and W. F. Ware. Pp.* 346. *Macmillan and Company Limited, London.* 1954. 16*s. net.*

This collection of some thousand examples, covering the usual courses in physics for the advanced level of the General Certificate of Education, differs from most other similar books in that the subject is divided into chapters, and that in each chapter the examples for practice are preceded by a brief theoretical introduction and some worked examples. Even though these introductions are often so brief as to degenerate into collections of formulae, these special features nevertheless add to the usefulness of the book.

Unfortunately the book is not as good as it might be. In general it barely reaches advanced level standard, and at some points it falls short of it. Subjects omitted completely include the method of dimensions, polarization, adiabatic expansions, self- and mutual inductance, and lines and tubes of force; there is no theory or worked examples on the wave theory of light nor on dielectrics. This list is by no means exhaustive.

But perhaps the most serious fault of the book is that there is no reference whatsoever to modern developments, in either the theoretical introductions or the worked examples. To give but one example—electrons are not mentioned at all. This is not the way to encourage the inquiring spirit in young physicists.

L. R. B. ELTON

### STRESS AND STRAIN

Analysis of Deformation, *Volume 2, by K. Swainger. Pp. xxxvi* + 365. *Chapman and Hall Limited, London.* 1954. 70*s. net.*

The first nine chapters of this second volume are concerned with theoretical and some experimental aspects of stress and strain. Chapter X (the best) treats the deformation of rubber, chapter XI the application of couples, and chapter XII the shearing of thin plane laminae. The author states that the book is concerned primarily 'with practical aspects . . . without unduly emphasizing the mathematics.' The reviewer finds that



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this is not so. For example, too much space is occupied with an explicit statement of the components of stresses in various co-ordinate systems, and general formulae abound on most pages. Some particular problems are worked out in detail, as in chapter XI; it is a pity that there is not more of this and less of generalities.

The book has been written because 'it proved impossible to have published a full account in the scientific journals.' This is, in the opinion of the reviewer, insufficient justification. It is noted that the book deals largely with matters which are controversial rather than with material which is widely accepted, and in many places the reader is left to form his own opinion. This situation is unusual in books on physics and engineering, and it is felt that such books should be reserved only for the publication of material which is reasonably firmly established. The book has what might be called a 'microstructure,' which is unnecessary. For about 350 pages of text there is a contents list occupying no less than sixteen pages, and the index runs to eleven pages. The explanation is the abundance of sub-headings, there being, for example, no fewer than seven of these on page 141. Six pages are used to state the principal notation, and the preface occupies eight pages. All this, together with the almost unnecessary mathematical appendix, goes to make what is an expensive volume.

L. S. GODDARD

### CRYSTAL LATTICE THEORY

Dynamical Theory of Crystal Lattices, *by Max Born and Kun Huang. Pp. viii + 420. Oxford University Press, London.* 1954. 50*s. net.*

Almost forty years ago, Professor Born published the first detailed account of this subject. In the intervening years he has been largely responsible for several reports making the theory up to date, but the latest of these is now twenty years old. In collaboration with Professor Huang he has now prepared the present volume, which is a new and comprehensive treatment and will undoubtedly remain authoritative for many years to come.

The subject of lattice dynamics suffers from the difficulty of sheer mathematical bulkiness. Most of the calculations are simple enough in principle, and may readily be written down for the case of a monatomic Bravais lattice, but the general formulae necessary to describe real physical systems are usually very unwieldy, involving summations over numerous indices and many different terms. The authors have made a considerable effort to achieve conciseness of notation; even so, expressions involving six or seven lines of type are not uncommon, and there are moments when one feels that one would like to be able to see more easily through the formalism to the basic algebra and the underlying physical ideas.

For this reason it is perhaps fortunate that we have here, in effect, two books under one cover. The first three chapters, written mainly by Professor Huang, deal in an elementary way with atomic forces, vibrations, and the elasticity and stability of lattices. The physical aspects are emphasized, and relevant experimental results are discussed. Many topics are reviewed, yet the argument has a satisfying unity which makes it easy to read, even for the nonexpert.

The second part (which represents the original nucleus of the book, as prepared by Professor Born) invokes full mathematical rigour; we are led from a quantum-mechanical assembly of nuclei and electrons, through the complexity of the method of long waves, to general formulae for the piezo-electric, pyro-electric, and optical phenomena. The detailed derivation of these formulae (many published here for the first time) will be of the greatest value to the specialist, and the ten appendices contain some elegant notes on the mathematical techniques used in the theory.

It may well be that the first part will be more widely read today; the rigorous treatment may prove the more permanent contribution. J. M. ZIMAN

### ORGANIC SYNTHESIS

Organic Syntheses, *Volume 34, edited by W. S. Johnson. Pp. vi + 121. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 28*s. net.*

Most organic chemists are already familiar with this series and will welcome this latest member. The present volume lists the preparations of thirty-six compounds, of which several are prepared in two or three stages, so that the actual number of preparations described is nearer fifty. As in the previous volumes, complete details are given of manipulation, techniques, sources of reagents, and any necessary precautions, so that no unforeseen difficulty should arise in repeating the experiments. In addition, notes on the preparation of the α:ω-dinitro derivatives of propane, pentane, and hexane are appended to that for 1:4-dinitrobutane.

Some of the compounds here described, such as *cyclo*heptanone and di-*tert*-butyl malonate, are clearly of importance as intermediates; others, such as 3-methylthiophen and azelanitrile, have been included mainly because they illustrate general reactions and procedures. The index is cumulative and covers volumes 30–34.

The high standard of previous volumes is maintained, and the present volume is a worthwhile addition to the series. J. F. W. McOMIE

### ORGANIC CHEMISTRY

Outlines of Organic Chemistry (*third edition*), *by E. J. Holmyard. Pp.* 492. *Edward Arnold (Publishers) Limited, London.* 1954. 16*s. net.*

Dr Holmyard is well known for his skill in using his wide knowledge of the history of chemistry for both enlivening his textbooks and making them more easily understood and memorized. In this book the author continually stresses the contributions made by individuals to the development of chemistry. A study of the impact of the personality of an investigator on his work is an inspiring theme and one of the best ways of introducing a student to the history of any science and of arousing his enthusiasm.

The question of how much 'special' work should be included in a book of this kind has, on the whole, been solved very satisfactorily, as indicated by the treatment of physical properties, stereoisomerism, tautomerism, valency, free radicals, and catalysis. By omitting the quite unnecessary questions after each chapter useful space could have been saved and utilized to provide a more extensive treatment of aromatic substitution. Moreover, work in this field has now gone too far to be dismissed as 'attempts to explain the direction of substitution.'

The reference to nitronium and nitracidium ions is, however, welcome and the emphasis laid on the natural occurrence of simple organic compounds will be most stimulating to all who are attracted by the impingement of chemistry upon other sciences.

F. CHALLENGER



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PORPHYRINS

Porphyrins, their Biological and Chemical Importance, *by A. Vannotti (translated by C. Rimington). Pp. xv + 258. Hilger and Watts Limited, London.* 1954. 50*s. net.*

Professor Vannotti explains in his foreword that the book is not 'a mere revision' of his earlier monograph (*Porphyrine und Porphyrinkrankheiten*, 1937). While the present book contains considerable extra material, which enhances its value over that of the 1937 monograph, too many of the arguments presented seem to take little or no cognizance of important work done since 1945 on porphyrin metabolism, largely with the aid of isotopic tracers. References to such work are made, but they are not adequately woven into the material presented. This has inevitably led to contradictions. Professor Vannotti appears, in fact, reluctant to part with his earlier views. For example, he states (p. 88) 'the conclusion seems warranted that the liver regularly transforms protoporphyrin into coproporphyrin . . .'; yet, in a brief summary (p. 31) of the studies by American and British workers using isotopes, is set out the opposite, and now generally held, view.

Clinical aspects of the various porphyrias are discussed fully and well; there are excellent descriptions of the symptoms, supported by case histories. The author's preoccupation with lactoflavin therapy is somewhat misleading, since its efficacy is by no means assured.

The book is well translated; it is, however, unfortunate that publication has been so long delayed. J. J. SCOTT

PREPARATIVE ORGANIC CHEMISTRY

Methoden der Organischen Chemie (Houben-Weyl), *4th revised edition, edited by Eugen Müller. Georg Thieme Verlag, Stuttgart. Volume II:* Analytische Methoden. *Pp. xxiv* + 1070. 1953. *DM* 139 *net. Volume VII, part* 1: Sauerstoffverbindungen II, Aldehyde. *Pp. xxiii* + 556. 1954. *DM* 82 *net. Volume VIII:* Sauerstoffverbindungen III. *Pp. xviii* + 776. 1952. *DM* 98 *net.*

The third edition of this compendium was esteemed second only to Beilstein in the library of the bench-working organic chemist, and it is safe to say that the new fourth edition, completely revised by an authoritative group of scholars under the leadership of E. Müller and supported by O. Bayer, H. Meerwein, and K. Ziegler, will take an even more definite place as a real essential for the investigator.

The main part of the work is to be devoted to methods of preparation which will be classified as general methods ranging over several groups, and also as the methods applicable to selected groups of organic compounds. Two volumes exemplifying the latter method of approach have now appeared, namely Volume VII, part I, oxygen compounds II (1954), and Volume VIII, oxygen compounds III (1952). The author of the former is Otto Bayer, who deals with the aldehydes in an exhaustive manner which is altogether praiseworthy. The special feature which marks the work is the profusion of examples of preparations and also the very full reference to the original literature, including that relating to patents. A greater stimulus to research than this compilation could hardly be imagined. Every organic chemist has been, is now, or will be, interested in aldehydes, and Dr Bayer tells us exactly what we want to know about them. It is one of the most intriguing monographs which the writer has been privileged to read.

The reviewer was specially interested in R. Criegee's article on the organic peroxides in the second of these two volumes. Though this, and probably all other sections, could not be regarded as exhaustively treated, there is very much that is both unfamiliar and suggestive of new ideas in this description of a field of growing industrial importance. The new Houben-Weyl makes its own characteristic contribution to our resources and does not clash with those other most valuable works of reference, 'Organic Syntheses,' 'Inorganic Syntheses,' and 'Organic Reactions.' Indeed, one is glad to note a considerable number of references to these series.

Volume II (1953) deals with analytical methods, both qualitative and quantitative. This volume of over a thousand pages has been compiled by some twenty-five contributors, and it appears to be a moderately complete account of the parts of the subject treated. It must be regarded as a work of reference; it is obviously a mine of information on available techniques. The ordinary organic chemist will browse most happily in the second section of part I, which deals with the determination of the most common functional groups.

This enterprise deserves the warmest encouragement, and the purchase of the parts as they appear is obligatory for scientific libraries serving schools of research, whether they be in universities or in industrial or government organizations. ROBERT ROBINSON

INORGANIC CHEMISTRY

Inorganic Chemistry (*sixth edition*), *by Fritz Ephraim. Edited by P. C. L. Thorne and E. R. Roberts. Pp. xii* + 956. *Oliver and Boyd Limited, Edinburgh.* 1954. 35*s. net.*

Unlike many textbooks, Ephraim improves with age. There is, as a matter of fact, not a great deal of difference between this edition and its predecessor of 1948. The general character of the book remains unaltered, and the prefaces to the two editions are almost identical. A number of new sections, important in their bearing on chemistry but concisely inserted into the old framework, succeed in bringing the text into line with modern developments without burying established principles of the subject under a mass of detail put in merely for the sake of its newness. Recent discoveries in the transuranic series of elements, a brief account of the clathrate compounds, and new work in the field of metal hydrides are naturally among the items so introduced. But the fact that the bulk of the text stands without the need of more than minor modification, in spite of the relatively enormous output of new factual material in the inorganic field, and also that the new items can be fitted in so conveniently without disturbing the general run of the text, shows that the original selection of basic material in the earlier editions was well made and that the arrangement lends itself to the process of making up to date.

The main revisions have been made in the fields of radioactivity and valency theory; in the latter the introduction of three pages on 'quanticule theory' is perhaps the most original feature of the edition. In the earliest editions it was not always easy to find what one wanted, but the pruning and revision necessary for the production of subsequent editions of not greatly increased size have resulted in a greater clarity, which is maintained in this edition also. Although they were good in the fifth edition, the actual printing and setting out of the text have been further improved; this makes the book pleasant to handle and read, while the price, although slightly increased, remains very moderate indeed. F. M. BREWER



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FLUORESCENCE

Fluorescence Analysis in Ultra-violet Light (*fourth edition*), *by J. A. Radley and J. Grant. Pp.* 560. *Chapman and Hall Limited, London.* 1954. 52*s.* 6*d.*

Fluorescence has something of magic in its appearance, eludes easy estimation, and has a very large measure of empiricism in its use. The subject has two sides, that of the fluorescence of highly purified chemical substances, from which alone a connection can be made with physical and chemical theory, and that of materials as they are usually found. Among pure chemical substances fluorescence is uncommon; in organic chemistry it is chiefly confined to molecules with certain types of ring structure. Materials such as paper, oils, fats, minerals, drugs, skin, and so on frequently show fluorescence to some degree, almost always due to minute quantities of fluorescent substances present with the main chemical components.

The fourth edition of this book, revised, partly rewritten, and with 'a good deal of dead wood cut out,' deals with the second aspect of the subject, and provides a wealth of details and references on the use of fluorescence observations over a wide range of applied chemistry. With the growth of the subject that wealth has become embarrassing, and the impression received by a newcomer may prove bewildering. The subject still remains one where individual experience coupled with the closest scientific scrutiny is the only way to avoid gross errors.

E. J. BOWEN

MOLECULAR THEORY

Molecular Theory of Gases and Liquids, *by J. O. Hirschfelder, C. F. Curtiss, and R. B. Bird. Pp. xxvi* + 1219. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 160*s. net.*

This is the most comprehensive account yet published of the molecular interpretation of the main physical properties of gases and liquids. The authors' own experience at the University of Wisconsin has been supplemented by the collaboration, on specific topics, of other experts, including J. de Boer of Amsterdam (quantum effects) and J. S. Rowlinson of Manchester (polar gases). The book ranges from fundamental theory and its detailed comparison with experiment, to illustrative examples and numerical problems, in a manner which should ensure its becoming a standard work of reference.

Apart from some preliminaries on classical, quantum, and statistical mechanics, two main sections deal with the equilibrium properties exemplified by the equation of state and with the transport phenomena of viscosity, diffusion, and thermal conductivity. Consistent use is made of the generalized principle of corresponding states in summarizing experimental data, which are then interpreted in terms of the various empirical functions for the potential energy of a pair of interacting molecules. A concluding section reviews our much less complete understanding of the theory of intermolecular forces. Chemical reactions are not specifically discussed, though a chapter on hydrodynamics includes flames, shock waves, detonations, and rocket propellents.

A valuable appendix provides tables by means of which the experimentalist or engineer can quickly estimate from fundamental constants many unknown quantities of practical importance.

K. W. SYKES

ORGANIC REACTIONS

Organic Reactions, *Volume* 8, *edited by Roger Adams. Pp. v* + 437. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 96*s. net.*

The appearance of a new volume of 'Organic Reactions' is always an important event for organic chemists. The project, due to Professor Roger Adams, of compiling critical discussions by recognized authorities of the more important organic reactions first bore fruit in 1942.

The value of these books to the chemist is threefold. In the first place, he is sure of a comprehensive and critical account of the scope and modus operandi of the reactions described. Secondly, he will find a comprehensive list of compounds prepared by the reactions described, together with references. Finally, particularly in the more recent volumes, there are stimulating discussions of reaction mechanisms. A readable, interesting style is preserved throughout.

The present volume, the eighth in the series, preserves the tradition of the earlier ones and will acquire the same esteem. It contains sections on catalytic hydrogenation of esters to alcohols; the synthesis of ketones from acid halides and organo-metallic compounds of magnesium, zinc, and cadmium; the acylation of ketones to form β-diketones or β-keto aldehydes; the Sommelet reaction; the synthesis of aldehydes from carboxylic acids; the metalation reaction with organolithium compounds; β-lactones; and the reactions of diazomethane and its derivatives with aldehydes and ketones. The admirable article on the acylation of ketones deals with reactions and compounds of great current importance and will be widely appreciated. The critical discussions on the mechanisms, particularly of the acid-catalysed cleavage of the Reissert compounds and of the Sommelet reaction, will also be welcomed.

D. LL. HAMMICK

PHYSIOLOGICAL CHEMISTRY

Practical Physiological Chemistry (*thirteenth edition*), *by Philip B. Hawk, Bernard L. Oser, and William H. Summerson. Pp. xvi* + 1439. *J. and A. Churchill Ltd., London.* 1954. 85*s. net.*

The present edition of 'Practical Physiological Chemistry' justifies in every way Dr Hawk's pride in his achievement in producing thirteen editions of the book in the course of the last fifty years. The esteem which the book has gained lies not only in the range and detail of its treatment of biochemical methods but in the freshness which revision has infused into each edition by the inclusion of the newest developments in biochemistry. Taken together, the several editions would provide interesting material for a study of the growth of biochemistry over the last half-century.

In its essential plan the present edition conforms to that of the more recent ones, except that theoretical aspects have gained greater recognition. In addition to descriptions of the conventional and established methods for the study of body tissues, fluids, and secretions which have made it an invaluable aid to teachers and clinical biochemists, the book includes description of the new techniques of biochemistry—ion exchange, counter-current distribution, paper chromatography, liver function tests, and so on. The vigour of the revision for this edition is well illustrated by reference to such matters as the helical structure of proteins, cobalamins, and thioctic acid, the succinct accounts of which many of the less academic biochemists will find helpful. Equally valuable are the numerous sections that deal with matters of clinical importance. Dr Hawk and his co-editors and collaborators can be warmly congratulated for this impressive new edition.

J. R. P. O'BRIEN



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MINERALOGY

Rocks and Mineral Deposits, *by Paul Niggli. (English translation by R. L. Parker.) Pp. xiii + 559. W. H. Freeman and Company, San Francisco; Bailey Bros. and Swinfen Limited, London.* 1954. 102*s. net.*

This book is for the student or research worker concerned with rocks and minerals; it would be of only limited value to other scientists wishing to learn something of these things. It follows an unconventional plan, but since the author was one of the great petrologists of this century it is of value to see the data presented in this way. The German edition was published in 1948, and this able translation by Professor R. L. Parker was done under the direct supervision of Professor Niggli, who was able to write a preface but died before the translation appeared.

An early section, and later a whole chapter, is devoted to the author's method of calculation of chemical analyses of rocks into standard minerals, and their graphical presentation. The book provides the most readily accessible explanation in English of this useful method. Whenever possible the author makes a quantitative approach to the subject with which he is dealing. He also makes a brave attempt to give precision to the description of the fabric of rocks. Only limited parts of his methods and ideas are likely to be generally assimilated into petrology, and in fact the author himself makes little use of these in his final chapters on a classification of the rocks.

L. R. WAGER

TRACE ELEMENTS IN SOILS

Geochemie seltener und nur in Spuren vorhandener chemischer Elemente im Boden, *by A. P. Winogradow. Pp. x + 250. Akademie-Verlag, Berlin.* 1954. *DM* 23 *net.*

Winogradow's book, published in Moscow in 1950, was the first comprehensive discussion of the distribution of trace elements in soils, and this German translation by Nikolai Ziabkin is welcome, as it makes the information much more readily accessible. The proportions of over thirty elements in some twenty Russian soil profiles, covering the major world soil groups, are discussed, and compared with values reported in the literature. In the main, only total contents are considered, and there seems to be a tendency to generalize on rather insufficient data. Following a detailed consideration of individual elements, the general principles applicable to different soil types are summarized in the final chapter. A few of Winogradow's ideas on the normal distribution of trace elements may give rise to some discussion, particularly among workers investigating soils which are somewhat younger and less fully developed than those of the Russian plains.

The translation has been rather uncritical, as many obvious numerical errors in the original are repeated without correction. Most of these are due to the unfortunate use of percentages rather than parts per million to indicate soil contents; 15 p.p.m., for instance, is expressed as $1{,}5.10^{-3}$ per cent, and mistakes often occur in the exponent. The reviewer has noted numerous such slips, and consequently doubt arises over the authenticity of other values which are not so readily checked. Misspellings of authors' names and misquotations of references are also rather abundant; nevertheless the book is a valuable addition to soil literature.

R. L. MITCHELL

GEOLOGY OF PETROLEUM

Geology of Petroleum, *by A. I. Levorsen. Pp. x + 703. W. H. Freeman and Company, San Francisco; Bailey Bros. and Swinfen Limited, London.* 1954. 68*s. net.*

A book on the geology of petroleum by A. I. Levorsen is an event, and those of us who were aware of its imminence looked forward to a treatise both comprehensive and authoritative. In this we have not been disappointed, for this volume covers every aspect of petroleum geology. Within its pages there is a vast array of factual information, brought together so admirably that it sheds light on every conceivable aspect of what has now grown to be the widest field of applied geology. Each chapter, moreover, includes a well-stocked bibliography to guide the student to a wider range of reading.

The author regards his subject primarily from the practical angle. To him, the essence of the duty of a petroleum geologist lies in the quest for more oil, and therefore he begins from the very outset to describe what are the essentials of an oil pool, and how its external and internal structure vary according to the natural forces which brought it into being. His sections dealing with the structural accumulation of oil and gas, and notably his chapter on the stratigraphic factors governing the accumulation of petroleum, are the highlight of the volume.

Later sections consider the relationship of water, oil, and gas, within the reservoir rock, followed by chapters devoted to sub-surface geology, petroleum provinces, and petroleum prospects.

The book will be welcomed by all students of the subject as an outstanding work.

V. C. ILLING

HISTOLOGY

Trattato di Istologia (*fourth edition*), *Volumes* 1 *and* 2, *by Giuseppe Levi. Pp. xvi* + 1171. *Unione Tipografico-Editrice Torinese, Turin.* 1954. 12 000 *lire net.*

The fourth edition of this textbook by the senior Italian histologist appears eight years after the third edition (1946). In line with the tradition of the German and Italian schools of medicine, it deals exclusively with the structural characteristics and biological properties of cells and tissues and not with the structure of the various organs; the only relevant exception is the structure of blood vessels, discussed in chapter 31.

The general pattern and guiding principles are basically the same as in previous editions. However, many important changes have been introduced and a good number of illustrations substituted or added. A concise review of the histochemical and histophysical techniques and of the tools for the investigation of microscopical and ultramicroscopical structures has been included. Mitosis, meiosis, the chromosomes, and the ultrastructure of the cytoplasm in general and of the various kinds of cells, have been dealt with more extensively than in the third edition.

Though the author gives his personal views on the various topics, facts, and opinions deriving from the contributions made by biologists of other countries are reported and objectively discussed throughout. No dogmatic statements, which often may seem inevitable in treatises written chiefly to meet the needs of students, are to be found. Professor Levi's book represents an invaluable guide also for the specialist histologist.

The list of references, set under thirty separate headings at the end of the second volume, will not only serve as an introduction to a more detailed bibliography but is in itself a rich source of information. A detailed subject index and an author index are also included. This very original book once again teaches the morphologist that the old



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and seemingly impenetrable barriers between neighbouring fields of biology must be broken down in order to get a deeper knowledge of living matter.

R. AMPRINO

BIOLOGICAL KINETICS

The Kinetic Basis of Molecular Biology, *by F. H. Johnson, H. Eyring, and M. J. Polissar. Pp. vii + 874. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 120*s. net.*

There can be no doubt today about the importance of the borderland between chemistry, physics, and biology, and this book is an important contribution to its study. The unifying theme is the application to a series of biological phenomena of principles and ideas derived from the theory of chemical reaction rates.

The book contains an immense amount of interesting and valuable material, and will be of interest and assistance to those who begin with some knowledge of the various specialized topics with which it deals, for example luminescence, membrane diffusion, muscle contraction, the nerve impulse, and drug action. In fact, for certain topics it constitutes something approaching a small reference work.

If it is true that a good many biologists chose their subject because they disliked mathematics they will find the first six chapters pretty tough going. These constitute in fact an advanced textbook of thermodynamics, and discuss quantum and statistical mechanics which most physical chemists will find demands their full attention. Then, on page 123, the book embarks upon a fairly elaborate review of the subject of luminescence, and follows with reviews of other subjects, in no very obvious order.

If a general criticism is to be made, it is perhaps that the liaison between the physico-chemical and the biological sides is not after all really very clearly brought out. It is perhaps most successfully achieved in chapters such as that on the effects of temperature, where numerous biological effects are treated under one physico-chemical heading.

For some interested in the very general kind of question discussed for example in Schrödinger's 'What is Life?', there may be a certain disappointment, especially if the name of at least one of the authors had led them to expect some bold and uninhibited reflections on these fundamental matters. But there is no reason for real complaint that the authors have chosen to plan their book as they have, and there is no doubt of its value.

C. N. HINSHELWOOD

MARINE BIOLOGY

Aspects of Deep Sea Biology, *by N. B. Marshall. Pp.* 380. *Hutchinson's Scientific and Technical Publications, London.* 1954. 35*s. net.*

'. . . contemporary science can be extremely beautiful though often very exasperating, and at times tremendous fun.' This quotation, cited by the author in his preface, is not only substantiated by the contents of the book itself, but may also account for the patently sincere and engaging style in which it is written. The work takes the form of a digest—a compendium of short and more or less self-contained articles, each dealing with a particular aspect of deep-sea biology, but skilfully arranged in sequence to constitute an orderly, well balanced, and comprehensive review of the subject as a whole. In keeping with this method of presentation, the many beautiful illustrations by the author's wife are identified by the chapter number of the text to which they relate; at the end of each chapter references are given to the authorities quoted. This book is specially worthy of commendation to the biological student as a sound and stimulating introduction to our knowledge and concepts of life in the ocean deeps, as revealed by scientific investigation since the world voyage of H.M.S. *Challenger* from 1872 to 1876. It can be equally commended to the intelligent lay reader for its informative and compelling reading.

E. FORD

INSECT METAMORPHOSIS

The Physiology of Insect Metamorphosis, *by V. B. Wigglesworth. Pp.* 152. *Cambridge University Press, London.* 1954. 12*s.* 6*d. net.*

Insect physiologists will be indebted to Professor Wigglesworth for this incisive survey of the progress that has been made in the study of insect metamorphosis. The rapid growth of interest in this field is well shown by the fact that of over four hundred publications reviewed almost one-quarter have appeared within the past five years. This monograph will be welcomed by both specialist workers and general readers as a timely statement of the present position.

In making his own well-known studies on the hormonal control of metamorphosis in *Rhodnius* its central theme Professor Wigglesworth has given his book authority and clarity. In regarding metamorphosis not as an extension of embryological development but as an expression of polymorphism he has given both renewed support to a theory due to Swammerdam and a stimulus to further inquiry.

In writing the first of a new series of Cambridge monographs in experimental biology the author has set a high standard which will cause further contributions to the series to be eagerly awaited. The monograph is well illustrated and its production is of the quality one has come to expect from the Cambridge University Press.

R. DENNELL

BOWER-BIRDS

Bower-Birds, *by A. J. Marshall. Pp.* 208. *Clarendon Press, Oxford.* 1954. 30*s. net.*

This book was much needed, for while bower-birds have often featured in discussions on evolution and behaviour, the facts and interpretations usually presented include many errors. After an introduction and two brief (but difficult) chapters on sexual physiology in birds, there follow eighteen chapters, each giving a straightforward factual account of one species of bower-bird, with special reference to its displays, bower, breeding, and development of sex organs. There is much first-hand observation and a good summary of the observations of others. A final chapter considers the evolution of bower-building.

This is a trustworthy account of what happens, and the book will therefore be of value to zoologists and also, one hopes, to amateur ornithologists, even though the author has unfortunately not attempted to simplify the language or presentation and introduces many technical physiological terms without definitions. But the tale that is told is astonishing. The bowers are of several patterns, which help in the classification of the species. The objects brought to them may be of restricted colours, which match colours on the female. The bowers may be stained—one of the few examples of the use of tools by birds. Some species are vocal mimics. The group offers a wonderful opportunity for future research.

D. LACK



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ENGINEERING

Dizionario d'Ingegneria, *Volume* 4 MOT–RUL, *edited by E. Perucca. Pp. viii* + 1040. *Unione Tipografico-Editrice Torinese, Turin.* 1954. 12 000 *lire net.*

As this impressive undertaking approaches completion it becomes increasingly evident how much care and forethought have gone into its preparation and how thorough the editor has been in collecting all terms relating not only to engineering but to all cognate subjects.

The first three volumes have already been reviewed in ENDEAVOUR with abundant praise and only minor criticisms, which apply also to this fourth volume.

As the pattern unfolds, the system adopted for sub-headings and cross-references appears more and more a complete success: one is reminded of the innumerable connections and ramifications of the nerve cells in the brain which serve to transmit information rapidly and efficiently.

Certain entries are covered most thoroughly: for instance, the seventy-six pages given to the various types of motors could hardly be bettered. In other cases, however, one would like to learn more: for instance, there is little about modern developments in the plastics industry. But some unevenness in a work which is the combined effort of 125 experts is of course inevitable.

Some users, particularly outside Italy, may regret that the French, English, and German equivalents are given for only a few terms: a more generous allowance of these equivalents would in fact have made the 'Dizionario' also a technical dictionary in four languages.

This is a magnificent work of reference which will rarely fail to provide anybody consulting it with the required information.

L. PINCHERLE

RARE METALS

Rare Metals Handbook, *edited by Clifford A. Hampel. Pp. xiii* + 657. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 96*s. net.*

This book is written by thirty-four contributors and contains chapters dealing with twenty-eight of the less common metals; the platinum metals and the rare earths are dealt with in single chapters. The book has many of the defects to be expected from such a wide joint authorship, and there is little or no general plan, except that the industrial methods of extraction and purification are described fully and a list of physical properties is given for each metal. Thus, the chapter on vanadium contains detailed tables of the properties of more than forty vanadium-bearing minerals, but for some metals the sources are only briefly summarized. The chapters are of very varying quality, but three general comments may be made. First, the main value of the book lies in the description of industrial methods for the extraction and purification of the metals, since this information is not easily accessible. Second, readers interested in the chemistry of the less common metals will be better advised to buy a standard textbook of inorganic chemistry, in which the facts will be seen as part of a general science. Third, the sections dealing with the present reviewer's interests—namely the properties and structures of metals and alloys—are sometimes inferior, unreliable, and out of date. Thus some lattice spacings are given in Ångström units when the values are really in kX units, while some values are given with no units indicated. Equilibrium diagrams of alloys are given for some metals only, and are often quite out of date. Any reader of the book will acquire much information, but it requires a thorough revision before it can be recommended as an authoritative source of numerical data.

W. HUME-ROTHERY

# Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

ASTRONOMY

Astronautica Acta, Volume 1, *edited by F. Hecht. Pp.* 60. *Springer-Verlag, Vienna; I. R. Maxwell and Company Limited, London.* 1955. 62*s. net per annum.*

BIOLOGY

Actions of Radiations on Living Cells (*second edition*), *by the late D. E. Lea. Pp. xiv* + 416. *Cambridge University Press, London.* 1955. 30*s. net.*

Annual Report of the National Oceanographic Council 1953–54. *Pp.* 28. *Cambridge University Press, London.* 1955. 5*s. net.*

BOTANY

British Mosses and Liverworts, *by E. V. Watson. Pp. xvi* + 419. *Cambridge University Press, London.* 1955. 45*s. net.*

Embryogenesis in Plants, *by C. W. Wardlaw. Pp. ix* + 381. *John Wiley and Sons Inc., New York; Methuen and Company Limited, London.* 1955. 42*s. net.*

CHEMISTRY

Biochemistry of Nitrogen (in honour of Artturi I. Virtanen). *Pp.* 535. *Suomalainen Tiedeakatemia, Helsinki.* 1955. *Paper covers,* $10*; bound,* $12 *net.*

Catalysis, Volume 2: Fundamental Principles (Part 2), *edited by P. H. Emmett. Pp. vi* + 473. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1955. 96*s. net.*

Chemical Process Principles: Part 1, Material and Energy Balances (*second edition*), *by O. A. Hougen, K. M. Watson, and R. A. Ragatz. Pp. xxxv* + 504. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 68*s. net.*

The Chemistry of Micro-organisms, *by A. Bracken. Pp. vii* + 343. *Sir Isaac Pitman and Sons Limited, London.* 1955. 30*s. net.*

The Chemistry of Petroleum Hydrocarbons, Volume 1, *edited by B. T. Brooks, C. E. Boord, S. S. Kurtz, and L. Schmerling. Pp. viii* + 664. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 144*s. net.*

Les Gaz Inertes; l'Hydrogène — Les Halogènes, *by P. Laffitte and H. Brussel. Pp.* 396. *Masson et Cie, Paris.* 1955. *Paper covers, fcs* 3600*; bound, fcs* 4200.

An Introduction to the Electronic Theory of Valency (*third edition*), *by J. C. Speakman. Pp. vii* + 180. *Edward Arnold (Publishers) Limited, London.* 1955. 10*s.* 6*d. net.*



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An Introduction to the Principles of Chemistry, *by L. H. Cragg and R. P. Graham. Pp. ix + 740. Clarke, Irwin and Company Limited, Toronto.* 1954. $7.50 *net.*

Journal of Inorganic and Nuclear Chemistry, Volume 1, Nos. 1–2, *edited by J. J. Katz, H. C. Longuet-Higgins, and H. A. C. McKay. Pp.* 164. *Pergamon Press Limited, London.* 1955. *Subscription A (normal)* 90*s. Subscription B (for subscriber's own use)* 70*s. per volume.*

A Manual of Paper Chromatography and Paper Electrophoresis, *by R. J. Block, E. L. Durrum, and G. Zweig. Pp.* 484. *Academic Press Inc., New York.* 1955. $8 *net.*

Monomeric Acrylic Esters, *by E. H. Riddle. Pp. vii + 221. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 40*s. net.*

Photosynthesis, *by R. Hill and C. P. Whittingham. Pp. vii + 165. Methuen and Company Limited, London.* 1955. 8*s.* 6*d. net.*

Synthetic Rubber, *edited by G. S. Whitby. Pp. xii + 1044. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 144*s. net.*

GENERAL

Biology as a Career (*second edition*), *edited by G. E. Fogg. Pp.* 40. *The Institute of Biology, London.* 1955. 2*s.* 6*d. net.*

Composition of Scientific Words, *by R. W. Brown. Pp.* 882. *Published by the author at the U.S. National Museum, Washington.* 1954. $8 *net.*

Deterioration of Materials, *edited by G. A. Greathouse and C. J. Wessel. Pp. xvii + 835. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 96*s. net.*

The Human Use of Human Beings (*revised edition*), *by Norbert Wiener. Pp.* 199. *Eyre and Spottiswoode (Publishers) Limited, London.* 1954. 18*s. net.*

The Scientific Journal of the Royal College of Science, Volume 24, *edited by B. W. Baker. Pp. vi + 122. Royal College of Science, London.* 1954. 10*s.* 6*d. net.*

Slovník Stavebné Mechaniky a Příbuzných Oborů v Pěti Řečích (Dictionary of Structural Mechanics, with keys in five languages), *by Z. Bažant. Pp.* 251. *Nakladatelství Československé Akademie Věd. Prague.* 1953. *Paper covers, Kčs* 15; *linen covers, Kčs* 20 *net.*

HISTORY OF SCIENCE

The Development of the Concept of Electric Charge: Electricity from the Greeks to Coulomb, *by Duane Roller and Duane H. D. Roller. Pp. iv + 97. Harvard University Press, Cambridge, Mass.* 1954. $1.60 *net.*

Oxford's Contribution to the Origins of Modern Science (a paper read to the British Association for the Advancement of Science at Oxford on 6th September 1954), *by A. C. Crombie. Pp.* 27. *Basil Blackwell, Oxford.* 1954. 2*s.* 6*d. net.*

Science and its Background (*second edition*), *by H. D. Anthony. Pp. ix + 337. Macmillan and Company Limited, London.* 1954. 20*s. net.*

MEDICINE

British Medical Bulletin, Volume 11, No. 1 (Blood Coagulation and Thrombosis), *edited by J. V. Dacie. Pp.* 82 + *xvi. The British Council, London.* 1955. 15*s. net.*

The Harvey Lectures (delivered under the auspices of the Harvey Society of New York 1953–1954). *Series XLIX. Pp. viii + 299. Academic Press Inc., New York.* 1955. $7.50 *net.*

Lehrbuch und Atlas der Anatomie des Menschen, Volume 1 (*nineteenth edition*), *by Fr. Kopsch. Pp. vii + 736. Georg Thieme Verlag, Stuttgart.* 1955. *DM.* 64.50 *net.*

Les Bactéries Lysogènes et la Notion de Provirus, *by F. Jacob. Pp. viii + 176. Masson et Cie, Paris.* 1954. *Fcs* 800 *net.*

The Mammalian Fetus: Physiological Aspects of Development (Cold Spring Harbor Symposia on Quantitative Biology, Volume XIX). *Pp. xii + 225. The Biological Laboratory, Cold Spring Harbor, New York.* 1954. $8 *net.*

Modern Medical Monographs 9: An Rh-Hr Syllabus: the Types and their Applications, *by A. S. Wiener. Pp. xii + 82. Grune and Stratton Inc., New York.* 1954. $3.75 *net.*

Patologia Generale, *by Vincenzo Bisceglie. Pp. xix + 1140. Casa Editrice Dott. Francesco Vallardi, Milan.* 1954. 10 000 *lire net.*

PHARMACOLOGY

Development of Veterinary Pharmaceutics, *by A. G. Fishburn and C. F. Abbott. Pp.* 23. *The Pharmaceutical Press, London.* 1954. 2*s.* 6*d. net.*

PHILOSOPHY

The Unleashing of Evolutionary Thought, *by O. Riddle. Pp. xxi + 414. Vantage Press Inc., New York.* 1954. $4.50 *net.*

PHYSICS

The Atom (*fourth edition*), *by Sir George Thomson. Pp. viii + 204. Oxford University Press, London.* 1955. 6*s. net.*

An Introduction to Stochastic Processes, *by M. S. Bartlett. Pp. xiv + 312. Cambridge University Press, London.* 1955. 35*s. net.*

Luminescence, with particular reference to inorganic phosphors. (*British Journal of Applied Physics, Supplement No.* 4). *Pp. iv + 120. The Institute of Physics, London.* 1955. 25*s. net.*

Relativity for the Layman, *by James A. Coleman. Pp.* 131. *The William-Frederick Press, New York.* 1954. $2.75 *net.*

Superfluids, Volume II (Macroscopic Theory of Superfluid Helium), *by the late F. London. Pp. xvi + 217. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 64*s. net.*

X-Ray Diffraction by Polycrystalline Materials, *edited by H. S. Peiser, H. P. Rooksby, and A. J. C. Wilson. Pp.* 725. *The Institute of Physics, London.* 1955. 63*s. net.*

TECHNOLOGY

Hot Dip Galvanising, 1954 (Third International Conference on hot dip galvanising held at Oxford 4th–9th July 1954). *Pp. ix + 268. Zinc Development Association, Oxford.* 1954. 42*s. net.*

Introduction to Nuclear Engineering, *by R. L. Murray. Pp. xiv + 418. George Allen and Unwin Limited, London.* 1955. 30*s. net.*

The Technology of Solvents and Plasticizers, *by A. K. Doolittle. Pp. xv + 1056. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 148*s. net.*

ZOOLOGY

Laboratory Explorations in General Zoology (*third edition*), *by K. A. Stiles. Pp. xi + 283. The Macmillan Company, New York.* 1955. $3.75 *net.*

Traité de Zoologie. Anatomie, Systématique, Biologie. *Vol. XII, Vertébrés, edited by Pierre-P. Grassé. Pp.* 1145. *Masson et Cie, Paris.* 1954. *Paper covers, fcs* 9800; *bound, fcs* 10 550.



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# ENDEAVOUR

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# Science and imagination

By those unfamiliar with it, science is commonly looked upon as a strictly objective and unimaginative pursuit in which the personality of the individual research worker is not reflected. Progress, it seems, is the result of faithfully following an established procedure, each new step forward being the logical and considered sequel to the one which preceded it. Casual perusal of the journals in which the results of new research are reported seems to confirm this. There, all follows a clear pattern: new facts are discovered by experiment or observation and then fitted neatly into a framework of unifying explanation. Yet how different, in most instances, is the reality. How often does the inspired guess—the product of some scientific instinct, partly inherent and partly bred of experience—reveal the truth long before it could have been uncovered by conventional methods. Claude Bernard was firmly of the opinion that ideas are of far greater importance than facts: '*on donne généralement le nom de "découverte" à la connaissance d'un fait nouveau; mais je pense que c'est l'idée qui se rattache au fait découvert qui constitue en réalité la découverte.*' Such ideas, of course, are not always right—and then we hear no more of them—but when they are they save a vast amount of time and effort, for only one possibility, and not many, needs to be confirmed.

Thus imagination, far from being unnecessary in science, is a most useful asset, and exceptional fertility of imagination is a quality which distinguishes the truly great scientist from his fellows. The history of science offers innumerable examples to support this thesis. Kekulé's imaginative conception of the quadrivalency of carbon and the union of carbon atoms, and his sudden vision of the benzene molecule as a snake seizing its own tail, come immediately to mind. The explanation of aberration came to James Bradley as he was sailing on the Thames. Today, when the pace of scientific progress has so greatly accelerated, too little time is given to exercising the imagination. There is much merit in Kekulé's advice: '*Lernen wir träumen, dann finden wir vielleicht die Wahrheit.*' Problems in mathematics, too, commonly resolve themselves more readily by intuition than by the logical application of established rules. Poincaré has described how a major discovery in the theory of fuchsian groups and functions, upon which he had long been pondering, came to him as he boarded an omnibus at Coutances; again, walking by the sea, he suddenly realised a property of indefinite ternary quadratic forms which had not hitherto been apparent. William Whiston has recorded that in mathematics Newton 'could sometimes see almost by intuition, even without Demonstration. . . . And when he did but propose conjectures in Natural Philosophy, he almost always knew them to be true at the same Time. . . .' Sir Charles Parsons related that his mathematical work was done by obscure mental processes which even he himself did not understand. Having reached the goal, it is sometimes easy to see how it could have been achieved by going from one firm stepping-stone to another. Sometimes, however, it is years before the intermediate steps are clear, but in the meantime the result may be put to use.

In science the means for progress often exist long before they are utilized; the facts necessary for the formulation of some important generalization may be common knowledge long before their collective significance is apparent. Here again it is the imaginative mind, rather than the logical, which perceives new significance and an underlying pattern in something known to all. Thus the fact that friction generates heat has been known from ancient times, for it is a primitive method of making fire, but it was Rumford who first clearly saw and formulated the significance of the relationship between work and heat. Anomalies in the eclipses of Jupiter's moons were well known before Rømer advanced the correct explanation, that light has a finite velocity. Giovanni Cassini, himself no mean thinker, had for a short time toyed with this hypothesis, but had discarded it, and he strongly opposed Rømer's theory when it was first enunciated. Such failure to perceive the force of new theories is by no means rare in the history of science. Thus Priestley remained a convinced phlogistonist until the day of his death, although his own experiments with red calx of mercury played no small part in leading Lavoisier to a true understanding of the nature of combustion. Such lack of understanding is particularly surprising, for Priestley himself condemned those unreceptive of new ideas: 'we may take a maxim so strongly for granted that the plainest evidence of sense will not entirely change, and often hardly modify, our persuasions.' What Priestley is condemning is, in effect, lack of imagination.

In the design of experiments imagination may play as vital a role as it does in the interpretation



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of results. '*Toute l'initiative expérimentale est dans l'idée, car c'est elle qui provoque l'expérience*,' wrote Bernard. The good experimentalist is he who, free from preconceived ideas, sees quickly and clearly what must be demonstrated and how it may most simply be done. Others might eventually reach the same conclusion, but with less elegance and more labour.

While the general progress of science depends upon the development of the original ideas of a comparatively few men, the work of development, too, demands considerable powers of imagination. The application of new conceptions, whether for the purposes of further research or for practical ends, almost invariably poses a variety of difficult problems. At all levels of science, both pure and applied, imagination plays an important role.

While a fertile imagination is thus not merely useful but essential, it is a characteristic which must not become dominant. Science itself is objective and not subjective, and while speculation may rightly form both prologue and epilogue to experiment, it can have no part in the latter, where objectivity is essential. Results which fail to fit in with preconceived theories must not be ignored unless some reason for the deviation is clear; as in the case of Jupiter's moons, it is often the discrepant result which is the most significant. Uninhibited speculation has no place in science, and it is very right that all new theories not fully substantiated by facts should be treated with reserve. While one might cite many examples of undeserved scepticism having delayed general acceptance of important theories, it must not be forgotten that the same scepticism has ensured the early death of innumerable ideas which were in fact worthless.

It is perhaps this ceaselessly questioning attitude of mind, coupled with the need for strict objectivity in the laboratory, which has led to the present popular conception of the scientist as an unimaginative being interested only in material matters. In a world growing daily more dependent upon the fruits of scientific research and their application, such conceptions, like all others which seem to set scientists apart from the rest of the community, are dangerous. Such misunderstanding breeds suspicion, and scientists, far from being looked upon as potential benefactors, are feared as possible instruments of suffering and destruction; as a result there is prejudice against their participating in the wider fields of human affairs. Clearly they must, as scientists, participate in such affairs only in so far as their special technical knowledge may be helpful; it cannot be argued that scientific knowledge alone is a qualification entitling its possessor to influence in fields where such imponderable factors as human emotions and desires play major parts. Yet imagination is among the most important qualities necessary for solving the grievous problems which beset the world today, and recognition of the fact that it is one which scientists may possess in considerable degree would surely encourage their useful employment in wider fields. But such a move demands support from both sides. The scientist must realize that unless he is speaking of purely technical matters he is entitled to a hearing only in respect of his other qualities. Equally, those responsible for the formulation of policy must more generally realize that the ability of scientists is not necessarily confined to purely scientific matters.

At the moment, unfortunately, the gap can be bridged only from the side of science. While many men trained in the discipline of science have subsequently proved their ability to assist in the formulation of policy and to undertake administration at the highest levels, the opposite transition is virtually unknown. For this state of affairs there is a good and obvious explanation: for social and economic reasons, specialized training, whether in science or anything else, is possible virtually only in early life. With the best will in the world, older men established in positions which oblige them to make major decisions relating to scientific matters cannot enter on a course of scientific study detailed enough to be useful. But the young scientist who has just completed his studies has a wide choice of useful careers in front of him if he and his prospective employers are willing to make his scientific training not his sole means of livelihood but a means of bridging the gap between science and the vast range of other affairs which it now influences. With a sufficiently large number of trained scientists thus placed in administrative posts the tide might eventually flow in both directions. Men trained in science and having experience of the practical problems of everyday affairs might eventually find their way back to the scientific world, with advantage to both.



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# Photosynthesis

C. P. WHITTINGHAM

The importance of increasing the world's food supply to keep pace with its rapidly increasing population, and of increasing its fuel supply to permit the vast industrial expansion upon which our modern standard of life depends, needs no emphasis. In both connections study of photosynthesis is of fundamental importance. Not only is it the process by which green plants produce our principal foodstuffs but it is a process by which solar energy is converted into chemical energy potentially useful for industrial purposes. Analysis of the successive reaction steps indicates that photosynthesis is probably not a biochemically unique process.

Early investigators of photosynthesis showed that a green plant exposed to light apparently reversed the ordinary process of respiration common to all living organisms—it took up carbon dioxide and water and produced organic compounds and oxygen:

$$CO_2 + H_2O \underset{\text{respiration (dark)}}{\overset{\text{photosynthesis (light)}}{\rightleftharpoons}} \text{Organic compounds } C + \tfrac{1}{2}O_2$$

In the leaves of some dicotyledons the organic compound can be detected as starch; in other leaves sugar accumulates; in some algae fats are formed. In green wheat leaves, protein formation is accelerated by illumination in the presence of carbon dioxide. The production of these diverse foodstuffs can be understood if we assume the initial product of photosynthesis to be a sugar occupying a central position in the metabolic pool, for example a triose. Fats, amino acids and proteins, sugars and carbohydrates, may be formed from such a triose by known enzyme mechanisms common to all living organisms.

The overall process of photosynthesis can now be split up into several reaction steps. First, the absorption of radiant energy by the pigment system; second, the stabilization of this energy in some chemical form; and, finally, the transfer of this energy for the reduction of carbon dioxide.

### THE PIGMENT SYSTEM

The pigment system concerned with photosynthesis in the green leaf is localized in ellipsoidal bodies within the cell, the chloroplasts. Within the chloroplasts the pigments are concentrated in the grana in disk-like regions; these are stacked like piles of coins, but are separated from each other by areas relatively free of pigment. In algae there is a greater diversity of chloroplast shape, but the basic structure is probably analogous. It is assumed that within the differentiated layers of the chloroplast the individual pigments are arranged in an organized manner. These pigments are of two types: blue-green chlorophyll *a* and yellow-green chlorophyll *b*, and the carotenoids, yellow xanthophylls and orange carotenes. When other pigments, such as the red and purple anthocyanins, are present, they are dissolved in the cell sap and play no direct part in photosynthesis. The algae show a greater diversity of carotenoid pigments, and the blue-green and red algae contain, in addition, representatives of a further class of compounds, the phycobilins. The phycobilins are soluble in water; the chlorophylls contain both hydrophilic and hydrophobic groups and are soluble in organic solvents; the carotenoids are soluble in fats. This diversity of properties indicates at least a two-phase system in the pigment centres in the chloroplast.

Within the grana the pigments are highly concentrated, perhaps as high as 0·1 molar. However, since the absorption spectrum of chlorophyll in the plant is simply related to that of chlorophyll in solution, excitation may still be regarded as an act of absorption by an individual molecule. There is evidence that in an organized structure of high pigment concentration, such as the grana, any individual excited molecule may transfer its energy to an adjacent molecule of the same or a different kind. The fluorescence yield of chlorophyll in the plant is about one-tenth or one-hundredth of that of chlorophyll in solution, indicating that the life of the excited molecule is such that about one hundred transfers is the maximum possible during the excitation period. Two lines of evidence indicate that such transfer of energy between molecules does occur.

If allowance is made for a shift in the wavelength for maximum absorption and for some broadening of absorption bands *in vivo*, the absorption and fluorescence spectra of a green cell can be related



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with a reasonable degree of certainty to the spectra of the pigments which can be isolated from it. When, however, the cell absorbs light of one wavelength, which *in vitro* would result only in fluorescence characteristic of one pigment, it is found that the light emitted contains fluorescence characteristic of a second pigment present. For example, in a suspension of diatoms illuminated with light of a wavelength which is predominantly absorbed by the carotenoid fucoxanthol, the fluorescence is similar in quality and intensity to that emitted when the exciting light is absorbed only by chlorophyll. In the cell, energy must therefore have been transferred from the fucoxanthol, which absorbed the light, to chlorophyll. Similarly, transfer of energy has been demonstrated from chlorophyll *b* to chlorophyll *a* in green algae, and from the phycobilins to chlorophyll in the red and blue-green algae.

Prior to studies of the sensitization of the fluorescence of one pigment consequent upon absorption by a second pigment, it had been shown that the photosynthetic efficiency of light absorbed by carotenoids in the green alga *Chlorella* was about half that of light absorbed by chlorophyll; light absorbed by fucoxanthol in diatoms was about as efficient as that absorbed by chlorophyll; and that of light absorbed by phycobilins in blue-green algae about as efficient as absorption by chlorophyll. It was found that in the red algae the efficiency of light absorbed by phycoerythrin was greater than that for light absorbed by chlorophyll; this was later found to be true also for the sensitization of fluorescence of chlorophyll. This has been attributed to the existence in the red algae of a form of chlorophyll, chlorophyll *d*, which is inactive with respect to both fluorescence and photosynthesis, but to which energy may be transferred; it is suggested that phycocyanin and phycoerythrin transfer excitation energy preferentially to chlorophyll *a*. The measurements indicate that transfer of energy must occur with high efficiency within the plant.

The mechanism of energy transfer is assumed to be that of inductive resonance. The excited molecule is associated with an electric field with vibration frequencies determined by that of the light emitted; if a neighbouring molecule is able to absorb energy of these frequencies, it may itself be excited. Thus, the necessary condition for energy-transfer is that the fluorescence spectrum of the excited molecule overlaps the absorption spectrum of the receiver. Using Förster's equation, L. N. M. Duysens [1] has shown that, with the concentrations of chlorophyll *a* and *b* found in *Chlorella*, we should expect almost complete transfer of excitation energy from *b* to *a*. This would result effectively in the absence of any fluorescence characteristic of chlorophyll *b*, and this is indeed so (figure 1). Similarly, it can be shown that the almost complete transfer of energy from phycoerythrin and phycocyanin to chlorophyll is not inconsistent with the theory of transfer by induced resonance.

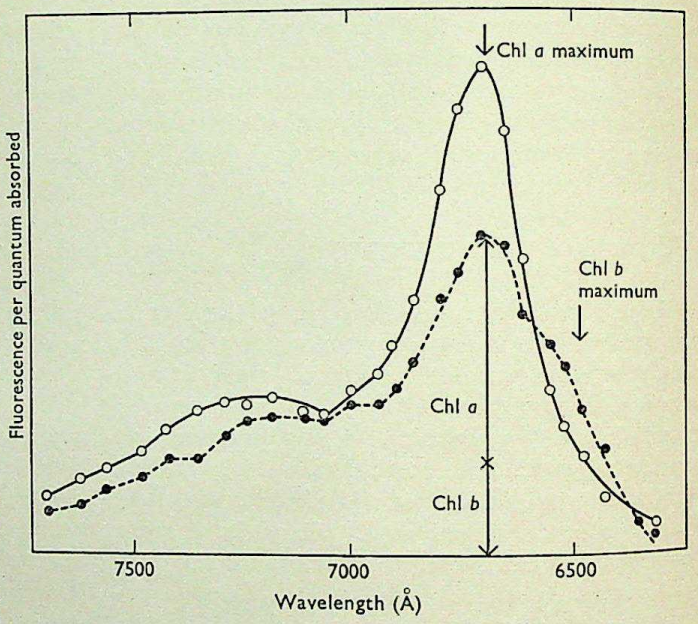


FIGURE 1 – *Energy transfer between pigments in solution. Fluorescence spectra for chlorophylls in ether solution when irradiated with a wavelength of* 4290 *Å* (70 *per cent absorption due to chlorophyll* a) *and with* 4530 *Å* (95 *per cent absorption by chlorophyll* b). *The vertical line at* 6700 *Å indicates that in the second case a large portion of the fluorescent light is characteristic of chlorophyll* a, *whereas chlorophyll* b *was the pigment excited: partial transfer of energy from chlorophyll* b *to chlorophyll* a *has taken place. In the living cell the pigments are more concentrated and transfer is practically complete.* o = *exciting light* 4290 *Å.* • = *exciting light* 4530 *Å.* (*From L. N. M. Duysens, Ph.D. thesis, Utrecht,* 1952.)

The pigment having an absorption maximum at the longest wavelength, chlorophyll *a*, is found in all plants except the bacteria; in the latter, bacteriochlorophyll plays a similar role. Thus all the pigments of the chloroplasts can ultimately contribute energy to chlorophyll *a*. The presence of a diversity of pigments merely extends the range of absorbed wavelengths effective in photosynthesis; this is a feature of some ecological significance in certain habitats.



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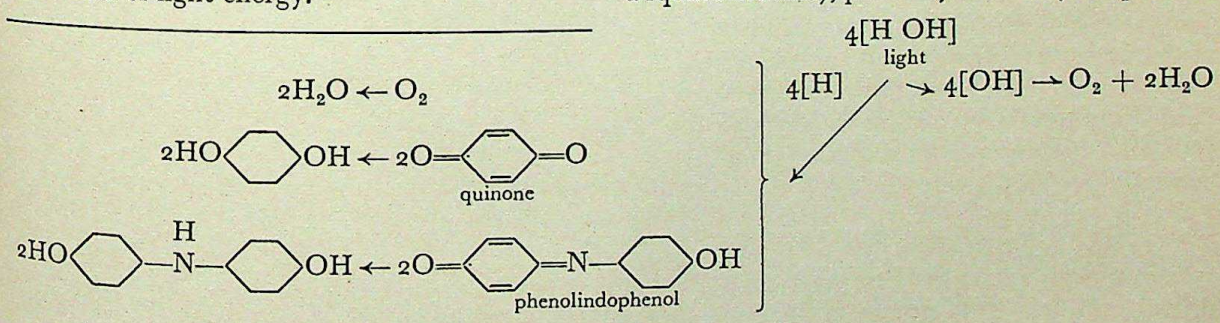
### ABSOLUTE QUANTUM EFFICIENCY

In contrast with the general agreement as to the relative efficiency of light of different wavelengths, there is not yet agreement about the absolute value for the maximum efficiency of photosynthesis. Values for the efficiency of conversion of free energy vary from 30 per cent up to 90 or even 100 per cent, i.e. a quantum yield in red light (6600 Å) of between 0·1 and 0·3 molecules $O_2$ per quantum. The majority of workers agree that the highest values are not firmly established; on the other hand, O. Warburg and his collaborators reaffirm their observations of high efficiency under a wide range of conditions [2]. Various suggestions have been put forward to explain this difference of opinion. The most probable is that many workers have used relatively brief light periods in order to make the correction for dark metabolism as precise as possible. During such periods, side reactions may play a role comparable with that of photosynthesis proper, vitiating the free energy calculation. Also, recent evidence has shown that *Chlorella* exhibits two morphological forms which differ in chlorophyll content and photosynthetic efficiency [3]; considerable variation in physiological properties also exists without change in gross morphology. Nevertheless, even accepting the lowest estimate, the efficiency of the overall process of photosynthesis in the living plant compares favourably with that of any other photochemical mechanism for the conversion of light energy.




General equation (A = acceptor):

$$4H_2O + 2A \xrightarrow{\text{light}} 2H_2O + O_2 + 2AH_2$$

### THE PRIMARY CHEMICAL STEP

The classical biochemical approach to the study of metabolism is to break up the cellular structure in an attempt to isolate individual reaction steps; the reaction system can then be ultimately analysed into pure chemical constituents. Using photosynthetic organisms, the only advance which has been made in this direction is the study of reactions catalysed by chloroplasts isolated from the cell. In the late nineteenth and early twentieth century it was thought that isolated chloroplasts were still able to carry on photosynthesis, though at a much reduced rate. In 1937 R. Hill [4] showed that isolated chloroplasts had no measurable affinity for carbon dioxide in the light; if, however, they were supplied with more easily reduced substances, such as ferric salts, instead of carbon dioxide, the ferric ion was reduced and oxygen was set free. It has now been shown that a variety of substances can be reduced—for example quinone, ferricyanide, and some dyestuffs—with the evolution of the equivalent amount of oxygen. This type of reaction is called the Hill reaction or chloroplast reaction. Under some conditions oxygen may itself act as a hydrogen acceptor, forming hydrogen peroxide; this breaks down to oxygen and water, resulting in no overall reaction. If the chloroplast reaction takes place in the presence of water labelled with $O^{18}$, it is found that all the oxygen evolved originates from the water, and none from the chloroplast material or from the substance reduced. The chloroplasts act only as a photocatalyst; they need not be complete, since fragments will suffice. Thus a general equation can be written representing the chloroplast reaction as a 'splitting' of water; water and the radicals are not postulated to exist in a free state but rather in the form of a complex (indicated in the equation by a square bracket), probably with enzymic protein.

If the direct reduction of certain biological substances, such as cytochrome or coenzyme I or II, is attempted using illuminated chloroplasts, little effect is observed, probably because of rapid reoxidation of any of the reduced form produced. But by coupling the chloroplast reaction with other systems in which the reduced form is rapidly



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consumed, and by maintaining a low concentration of oxygen, indirect evidence for reduction is obtained. By using the reaction systems shown in the following equations, W. Vishniac and S. Ochoa and others [5] demonstrated the reduction of both coenzyme I and coenzyme II in the chloroplast reaction.

$$H_2O + CoII \xrightarrow[\text{chloroplast}]{\text{light}} CoIIH_2 + \tfrac{1}{2}O_2$$

$$\text{Pyruvate} + CO_2 + CoIIH_2 \xrightarrow[\text{enzyme}]{\text{malic}} \text{Malate} + CoII$$

$$\text{Pyruvate} + CO_2 + H_2O \longrightarrow \text{Malate} + \tfrac{1}{2}O_2$$

$$H_2O + CoI \xrightarrow[\text{chloroplast}]{\text{light}} CoIH_2 + \tfrac{1}{2}O_2$$

$$\text{Pyruvate} + CO_2 + CoIH_2 \xrightarrow[\text{dehydrogenase}]{\text{lactic}} \text{Lactate} + CoI$$

$$\text{Pyruvate} + CO_2 + H_2O \longrightarrow \text{Lactate} + \tfrac{1}{2}O_2$$

If mitochondrial preparations from plant or animal tissue are added to illuminated chloroplasts, oxidative phosphorylation results. It is assumed that this represents a coenzyme coupled system, reduction of the coenzyme by the chloroplast system being followed by reoxidation of the reduced coenzyme via mitochondria, resulting in phosphorylation.

Thus the chloroplast reaction system represents, upon illumination, a potential supply of hydrogen in the form of reduced coenzyme and thence also of phosphorylated esters. Assuming these to be the products of the photochemical or water-splitting reaction, we may next consider how they are related to carbon dioxide fixation.

### THE FIXATION OF CARBON DIOXIDE

The availability of the relatively long-lived tracer $C^{14}$ enabled M. Calvin and his colleagues to advance earlier researches which had been limited to the use of the short-lived tracer $C^{11}$ [6]. The earlier work showed that if $C^{11}O_2$ was supplied in the dark to a green plant, activity appeared largely in carboxyl groups; under illumination, compounds largely free of carboxyl groups were labelled. In later experiments with $C^{14}O_2$, the analysis of products was made easier by the advent of new paper-chromatographic methods. This provided an analytical technique sufficiently delicate for the exploitation of the great sensitivity of the tracer method. The technique has been applied mainly to *Chlorella* and other algae, but some observations have been made with higher plants. After exposure to $C^{14}O_2$, the plant was rapidly killed in boiling alcohol and extracted successively in 80 per cent and 30 per cent alcohol, and the combined extracts were concentrated in vacuo. Two-dimensional paper chromatograms were then run, and active spots were identified by autoradiographs. After periods of illumination lasting several minutes, a large variety of carbon compounds, including sugars, fats, and proteins, showed radioactivity. As the period of illumination was shortened, the number of labelled compounds diminished, and at first it was argued that, in the limit, the compound in which activity first appeared must be the first product of photosynthesis. Later, curves were obtained in which the activities of individual compounds (as a fraction of the total carbon fixed) were plotted against time, and the curves were extrapolated to zero time (figure 2). Such curves clearly indicate that phosphoglyceric acid (PGA) is the first detectable compound to be labelled, and amounts to three-quarters of the total carbon fixed after two seconds illumination. Other compounds labelled at the outset include malic acid, free glyceric acid,

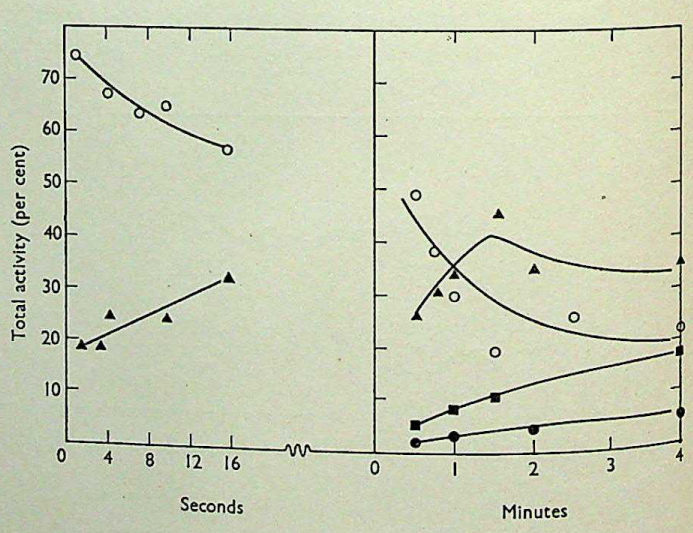


FIGURE 2 – *The percentage radioactivity incorporated in different compounds as a function of time during photosynthesis in* Scenedesmus *in presence of* $C^{14}O_2$. o = *phosphoglyceric acid.* ▲ = *sugar phosphates.* ■ = *malic and aspartic acids.* • = *alanine.* (*After Calvin, M., Bassham, J. A., Benson, A. A., Lynch, V. H., Ouellet, C., Schou, L., Stepka, W., and Tolbert, N. E., in* Symp. Soc. exp. Biol., 5, 284, 1951, *and Bassham, J. A., Benson, A. A., Kay, L. D., Harris, A. Z., Wilson, A. T., and Calvin, M., in* J. Amer. Chem. Soc., 76, 1760, 1954.)



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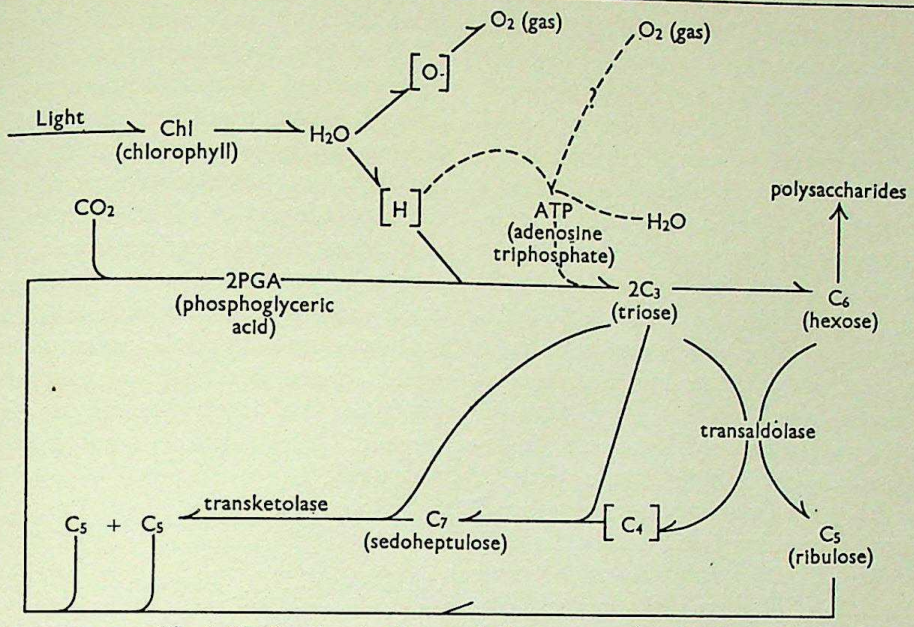


FIGURE 3 – *The path of carbon in photosynthesis as proposed by Calvin and colleagues.*

phospho-enolpyruvic acid, and a small amount of sugar phosphate esters. When the time of illumination is lengthened, the relative activity of PGA falls rapidly; that of some other compounds, e.g. phospho-enolpyruvic acid, increases to a maximum and then subsequently falls; a third group, represented by sucrose and alanine, shows a continuous increase. It is argued that the latter group represents final products, the second intermediates, and the first initial products.

For short periods of illumination, the radioactivity in PGA is confined to the carboxyl group, suggesting that it is formed by addition of carbon dioxide to some carbon precursor. Later the molecule becomes uniformly labelled, indicating the regeneration of further precursor containing the carbon dioxide already incorporated. An indication of the nature of this precursor has come from a study of the labelling sequence in the other compounds that are labelled early in illumination. Hexose is initially labelled in carbon atoms 3 and 4, and later in all six; thus the hexose probably arises from PGA. Sedoheptulose phosphate is at first labelled in carbon atoms, 3, 4, and 5 and ribulose phosphate in carbon atoms 3 and, to a lesser extent, 4 and 5. Thus the ribulose cannot arise directly from hexose, but must come from the 7-carbon compound. The following equations indicate the mechanism proposed by Calvin, which is summarized in figure 3.

$$3C_5 + 3C^*O_2 \rightarrow 6PGA\ (C_3C_2C_1^*) \ldots\ldots\ldots\ldots\ldots (1)$$

$$PGA \rightarrow \text{triose phosphate}\ (C_3C_2C^*) \rightarrow \text{hexose}^1\ (C_3C_2C_1^*C_1^*C_2C_3) \ldots (2)$$

$$\text{hexose} + 2\ \text{triose} \rightarrow \text{pentose} + \text{sedoheptulose} \ldots (3)$$

$$C_1C_2C_3^*C_4^*C_5C_6 \quad C_3C_2C_1^* \quad C_3^*C_2C_1C_5C_6 \quad C_1C_2C_3^*C_4^*C_1^*C_2C_3$$

$$\text{sedoheptulose} + \text{triose} \rightarrow 2\ \text{pentose} \ldots\ldots\ldots\ldots\ldots (4)$$

$$C_1C_2C_3^*C_4^*C_5^*C_6C_7 \quad C_3C_2C_1^* \quad C_1C_2C_3^*C_4^*C_5^* \quad C_3C_2C_1^*C_6C_7$$

Kinetic evidence for such a mechanism was obtained from a suspension of *Chlorella* by rapidly reducing the concentration of carbon dioxide during photosynthesis; a rapid increase in labelling of 5-carbon compound resulted, while the 3-carbon compound diminished. Further, after illumination ceased, there was a fall in 5-carbon compound labelling, together with an increase in that of the 3-carbon compound. These experiments clearly show an interrelation between the 3- and 5-carbon compounds. The enzymes which catalyse reactions (3) and (4), transaldolase and transketolase respectively, have been obtained from spinach leaves. Calvin and colleagues [7] have prepared sonic extracts from *Chlorella* which in the dark will fix carbon dioxide when supplied

[1] The number of any carbon atom in the product is that which it had in the reactant. Thus in hexose, atoms 1, 2, and 3 arose from one molecule of triose and 4, 5, and 6 from a second: hence it is written $C_3C_2C_1C_1C_2C_3$.



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with ribulose diphosphate, and will form PGA. This represents evidence for reaction (1). E. Racker [8] has shown that homogenates of spinach leaves can catalyse in the dark the conversion of carbon dioxide to carbohydrate if adenosine triphosphate (ATP), ribose phosphate, and reduced coenzyme are supplied. Thus a reasonable mechanism consistent with all the known facts may be developed for the incorporation of carbon dioxide into sugars. It follows that the function of light-energy is to supply reduced compounds, such as reduced coenzyme, and a means for phosphorylation of sugar derivatives.

The possibility remains that important intermediates in photosynthesis may not appear in tracer studies if they are present only in very small amounts or if activity is localized within the cell. There is also the difficulty, universal with tracer methods in this field, of distinguishing components labelled by a pathway unrelated to photosynthesis but nevertheless affected by light. In *Chlorella* a large metabolic pool of carbon compounds is filled under dark aerobic conditions; upon illumination a 'burst' of evolution of carbon dioxide takes place which is probably related to the 'dark' pool [9]. The substances concerned have not yet been chemically identified, but it appears very probable that they are different from those postulated by Calvin in his present scheme. We might then distinguish a light-cycle of 3-, 5-, and 7-carbon compounds from, for example, the well known Krebs dark cycle of 2-, 4-, and 6-carbon compounds. The present position offers great encouragement for a systematic study of enzyme systems concerned with carbon fixation in the green plant.

### THE ROLE OF CHEMOSYNTHESIS IN PHOTOSYNTHESIS

The mechanism of production of the phosphate esters which are probably concerned in the photosynthetic fixation of carbon dioxide is not yet known. There is evidence that in *Chlorella* the amount of ATP increases during illumination [10]. Comparative biochemistry suggests that ATP might arise from an oxidative process, the substrate for which could be part of the reduced product formed in the chloroplast reaction. As mentioned previously, additions of mitochondrial preparations to illuminated chloroplasts results in the formation of ATP. A cytochrome peculiar to green tissues, cytochrome *f*, has been obtained in relatively pure form; it is possible that this may play a role in photosynthesis in the reoxidation of reduced substances with the generation of ATP.

D. I. Arnon and colleagues [11] have recently demonstrated that chloroplast preparations from spinach leaves, carefully isolated so that the whole chloroplast is preserved (most previous workers used fragmented chloroplasts), are able to catalyse the formation of ATP from inorganic phosphate and adenosine monophosphate (AMP) at a rate four to twenty times greater in light than in dark. Such preparations also fix labelled carbon dioxide and have resulted in the recent claim that chloroplasts separated from the cytoplasm are able to complete the whole photosynthetic reaction sequence. The reaction steps shown below were proposed:

$$H_2O \xrightarrow[\text{chloroplast}]{\text{light}} 2e + 2H^+ + O \quad \ldots(5)$$

$$AMP + 2H_3PO_4 + 2e + 2H^+ + O \rightarrow ATP + H_2O \quad \ldots\ldots\ldots\ldots(6)$$

$$AMP + 2PO_4 \rightarrow ATP$$

Work is continuing to identify the compounds in which the tracer carbon is incorporated. An attempt is also being made to separate, if possible, the enzymic system concerned with phosphorylation from that concerned with carbon reduction.

The mechanism suggests two possibilities. The first is that oxygen is liberated in reaction (5) and reconsumed in reaction (6). In this case, reaction (6) would be analogous to the overall reaction in chemosynthetic organisms, i.e. organisms which obtain the whole of their energy for carbon dioxide reduction from the oxidation of some chemical substance, such as $H_2S$, present in their environment. Warburg and his collaborators favour such a chemosynthetic mechanism in photosynthesis in *Chlorella*, because they find that brief alternate periods of light and dark result in changes in the rate of oxygen production and consumption which might be interpreted as being due to the gradual development in light of an oxygen-consuming reaction followed by a general decay in the dark. A second alternative appears more probable. Oxygen, as such, need not itself be utilized for the formation of ATP, but rather the oxidized radical formed from the 'splitting' of water. In support of this view, A. H. Brown [12] has shown, using isotopes of oxygen, that the consumption of oxygen from the gas phase by *Chlorella* is unchanged as a result of illumination (figure 4). Arnon has also recently shown that phosphorylation during illumination by whole chloroplast preparations proceeds more rapidly under anaerobic



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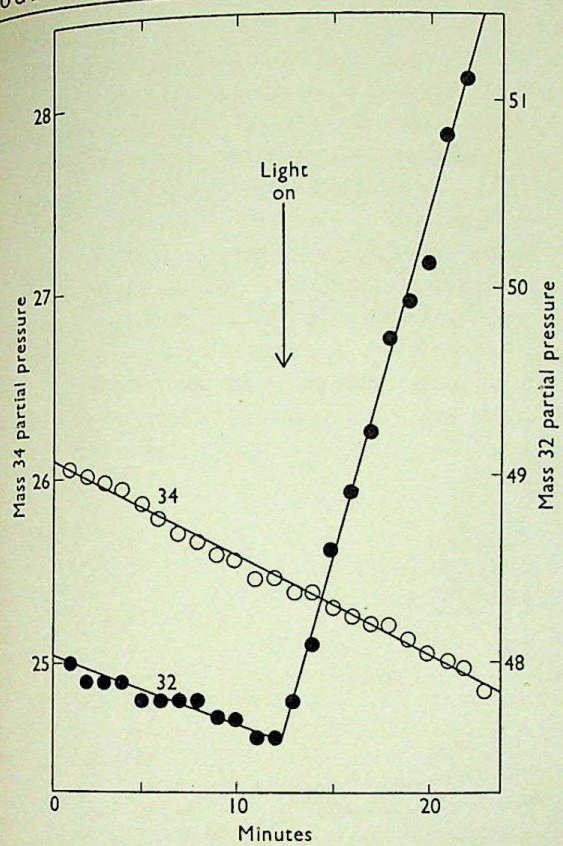


FIGURE 4 – *Differentiation between the simultaneous processes of oxygen uptake due to respiration and of oxygen production due to photosynthesis in light, using oxygen isotopes. $O^{34}$ was present in the gas phase, and its consumption is proportional to the rate of respiration. $O^{32}$ was present in the water also and is consumed in the dark, but consumed and produced in the light due to 'water splitting' in photosynthesis. Calculation shows that the rate of oxygen consumption is unchanged by illumination. (From van Norman, R. W., and Brown, A. H.,* Plant Physiol., 27, 691, 1952.)

than under aerobic conditions. This implies not only that oxygen is unnecessary, but that it is, in fact, inhibitory; this is possibly due to the reoxidation of reduced intermediates by an alternative pathway. Frenkel [11] has shown the same to be true for preparations from the photosynthetic bacterium *Rhodospirillum rubrum*.

Information about the ratio of the oxidized to the reduced forms of certain hydrogen carriers *in vivo* can be obtained if the two forms differ in their absorption spectrum. Duysens [13] examined the change in the absorption spectrum brought about by illumination of a *Chlorella* suspension, and found a change in absorption in the visible spectrum, which could be interpreted as an increased ratio of oxidized to reduced cytochrome *f*, together with changes in the ultra-violet spectrum, which could be due to an increase in reduced coenzyme. The data are such that the interpretation is equivocal; it is, however, consistent with our general concept of the mechanism of photosynthesis. Similar effects have been observed by H. T. Witt [13], who suggests, however, that the changes in absorption by *Chlorella* consequent on illumination may be related to the excited states of chlorophyll.

The time courses of oxygen production and carbon dioxide consumption during the first minutes of illumination show a close relationship; it is somewhat closer than might be expected *a priori* if water-splitting and carbon reduction represent two independent reaction systems. It appears possible that in the living cell there is an obligatory rate-coupling between the two systems, due to the need for ATP in the reduction cycle and its generation from the oxidized radical produced from water.

## PROBLEMS FOR THE FUTURE

The mechanism discussed is not to be considered as rigorously established; rather it begins to show how photosynthesis is taking its place in the general field of biochemistry. Photosynthesis no longer appears as a process unique to green plants: it appears to proceed in a manner which the modern biochemist might have predicted. But further observations are needed. Perhaps it is that one not only looks for an interpretation consistent with what is already known, largely from studies of dark metabolism, but ignores unidentifiable spots on the chromatograms which could hold the secret of any unique characteristic of photosynthesis.

It is certainly true that where comparative biochemistry ceases to help, in the borderland between the physics and the chemistry of photosynthesis, we know least about possible mechanisms. How excitation energy is first fixed in a chemical form remains a problem. Reduced coenzyme may represent the final product of a whole sequence of hydrogen transfers interposed after the water-splitting. A search is now in progress to find whether any carriers or specific catalysts concerned in such a transfer can be isolated from green plants. Hill and his collaborators [14] have isolated, in impure form, a protein which permits hydrogen transfer from the chloroplast system to addition reagents which are inert in the absence of the protein.

In a stimulating, but speculative, discussion Warburg [15] has suggested that a carotenoid acts as a hydrogen carrier between water-splitting and


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the reduction of coenzyme. This view is based on experiments in which it was shown with *Chlorella* that the photosynthetic efficiency in red light was apparently increased by previous exposure to blue-green light; further, inhibition of photosynthesis by *o*-phenanthroline—a metal-chelating agent—was overcome by illumination with blue-green light. Warburg interprets these observations in terms of *Photosynthese-Fermente*, probably containing metal groups, which are preferentially activated by blue-green light. Many further observations must be made to test this hypothesis.

Physiological investigations relevant to this matter are those which determine the photosynthesis resulting from very brief light-flashes [16]. If *Chlorella* is illuminated by flashes of less than $10^{-4}$ second duration, the oxygen evolved depends on the length of dark-time between flashes, and reaches an asymptotic value independent of the intensity of the flash. Thus there is a limited amount of energy which can be fixed during a single flash; this may be due to a limited amount of carrier substance which, once charged up, must be allowed sufficient dark-time to discharge before it can be charged again. The amount of this substance corresponds to one molecule per two thousand molecules of chlorophyll. The chemical identity of this carrier is not known.

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# The history of garden roses

ANN WYLIE

The rose is unique among garden flowers—unique in its universal appeal and its seemingly endless variety of form and colour. Yet, although there are over a hundred species of wild roses, the great majority of the varieties now grown are derived from only six of them. This article reviews the origins of roses and the principal methods used in their development, and the underlying genetic principles, understanding of which is enabling the work increasingly to be put on a systematic rather than its formerly wholly empirical basis.

The early history of garden roses, like that of so many groups of cultivated plants, is obscure. However, as M. B. Crane [1] has shown, modern genetical and cytological studies can give us a clear understanding of the way in which the present-day cultivated varieties of, for instance, wheat, tobacco, strawberries, and plums must have been developed. The same type of study has yielded much information on the origin of many groups of ornamental plants.

The chief processes concerned in this evolution have been classified by Crane under the following headings: (*a*) Gene mutation. (*b*) Simple autopolyploidy, that is, chromosome doubling in a normal non-hybrid plant: this frequently results in increased flower-size and substance, as in the recently introduced artificial tetraploids of Antirrhinum and Salvia. (*c*) Interspecific hybridization. (*d*) Interspecific hybridization accompanied by chromosome doubling (allopolyploidy). Most interspecific hybrids show varying degrees of sterility, and doubling the chromosome number of such hybrids frequently brings about a restoration of fertility, as well as the general increase in size due to polyploidy. Examples of all these types of change can be seen in the development of the garden roses of today. As C. C. Hurst [2] and others have pointed out, this development can conveniently be considered in two parts, one prior to 1800, during which the groups of so-called old-fashioned European roses came into being, and the second, from 1800 to the present day, which began with the introduction to western Europe of perpetual-flowering roses from the Far East.

There is comparatively little precise knowledge of how the various groups of old-fashioned roses developed. Hurst gives an admirable summary of the available data. The most important ancestral species for all the groups is *Rosa gallica*, the French Rose, indigenous in southern Europe and western Asia. Figure 1 is taken from Redouté's great work, *Les Roses*, and shows a single-flowered form of *R. gallica* which is probably very close to the wild species. The species is a tetraploid with twenty-eight chromosomes, as are the cultivated *gallica* varieties and also the very closely related groups of Damask, Centifolia, and Moss Roses. *R. gallica* is an immensely variable species, and numerous mutations affecting, in particular, the colour and degree of doubleness of the flower have been preserved in cultivation until this day. It is also very fertile, and many varieties were produced by hybridization of distinct forms and by selection among the progeny. Deliberate hybridization did not start until the eighteenth century, when Dutch, and later French, horticulturists took part in the work. Early in the nineteenth century more than a thousand varieties were known, though few still survive.

The origin of the cabbage roses (Centifolias), is unknown. *R. gallica* is undoubtedly one of the ancestral species, and, like this species, almost all the Centifolia varieties are tetraploids. The first, dating from the early eighteenth century, were completely double-flowered, with all the stamens converted into petal-like structures and with imperfectly developed carpels. It was therefore impossible to breed from them, and for a long time the sole source of new varieties was bud mutation, that is, a gene mutation occurring in a somatic cell. If this occurs sufficiently early in the development of a bud, then the greater part of the shoot later produced may have the altered genetic constitution. At the beginning of the nineteenth century a single-flowered mutation occurred which made hybridization with other groups possible. One of the notable mutations in the Centifolias is that which was responsible for the development of the moss character. This involved the formation of complex glandular hairs on flower stalk, ovary wall, and sepals, extending in some moss roses to the young stems and leaves as well.



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The small group of Alba varieties, which includes the white rose of York, is much more distinct than are the other European rose groups. The Albas are hexaploids, with 42 chromosomes, and the group originated through some chance hybridization between one of the white-flowered dog roses (whose female gametes contain 28 chromosomes) and *R. gallica*.

All these old European roses had but one period of flowering, in early summer, except for a few damask varieties which produced a sporadic crop of flowers in the autumn. However, perpetual-flowering roses occur in the section Chinenses of the genus. This contains the diploid species *R. chinensis* from China and *R. gigantea* from Burma; figure 4 is an illustration of the latter from Ellen Willmott's 'The Genus *Rosa*.' The Chinese had been growing roses for many centuries when regular trade with the West became established in the eighteenth century, and it was cultivated Chinese roses, probably many generations removed from the wild *R. chinensis* and *R. gigantea*, that were then brought back to England. Only four of these introductions seem to have taken part in the subsequent development of our modern roses, and a full description of these 'Stud Chinas' is given by Hurst [2]. Two are shown in figures 7 and 2: *R. semperflorens* (introduced in 1792) from an illustration in an early number of Curtis's *Botanical Magazine*, and 'Parsons' Pink China' (1793), from Redouté. The remaining two varieties, now extinct, showed a preponderance of characters from *R. gigantea*, and these, respectively pale pink and pale yellow in colour, played a prominent part in the development of the tea roses.

Very soon after the establishment of the Chinese roses in Europe, hybridization with the existing European roses began. A number of stages in this process can be distinguished. The first crosses resulted in two very distinct groups, the Noisettes and the Bourbons. The former came from a cross between the Pink China and the Musk Rose *R. moschata* (illustrated in figure 3, from Redouté). This diploid species is a climber with clusters of sweetly scented flowers, and is fairly closely related to *R. chinensis*. The initial hybrid, raised in America, was summer-flowering like the musk rose, the perpetual-flowering gene being recessive. However, in later generations bred by M. Noisette in France recombination yielded perpetual-flowering derivatives, one of which is shown in figure 5, from Redouté. These early Noisette varieties were also back-crossed to the Chinese roses, producing plants with larger flowers, more like the Tea roses. Some of these, such as Maréchal Niel and William Allen Richardson, are still grown today. The Noisettes are diploids like their ancestral species.

The Bourbon group stemmed from an accidental cross between the Pink China and an old damask rose which occurred about 1815 in Réunion Island, then known as l'Île de Bourbon. A group of vigorous shrub roses with large, beautifully scented flowers developed from crosses of the original hybrids with the Gallicas and damasks. One of the early varieties is shown in figure 6, from Redouté. Bourbons still grown today include Souvenir de la Malmaison, Zephyrine Drouhin (both triploids), Louise Odier, and Madame Pierre Oger (tetraploids). Bourbon roses were also concerned in the development of the later group of Tea roses, since many of the pink tea varieties trace back to a cross between a Bourbon and a derivative of *R. gigantea*. Further development in the Tea rose class came from intercrossing these Bourbon-teas with the Noisette-teas referred to above. Between 1850 and about 1890 this yielded many varieties noted for their abundance of large, beautifully formed, and highly scented flowers. But these tea roses were not especially hardy in England and northern Europe. Well known varieties are Marie van Houtte, Safrano, and Perle des Jardins, while the climber Gloire de Dijon is intermediate between the Noisette and Tea rose classes.

The important Chinese introductions were also crossed directly with Gallicas and other European roses, yielding the so-called Hybrid Chinas, summer-flowering shrub roses prominent in the first half of last century. These were mainly triploids and hence very sterile, but an important 'break' occurred about 1830 with the appearance of fertile tetraploids, for example Malton and Athalin. Interbreeding of these tetraploid hybrid Chinas with the later Bourbon varieties (also tetraploid) and the Portland roses (a small group originating from *R. chinensis* and Autumn Damask) produced the somewhat heterogeneous collection of roses known as Hybrid Perpetuals, which were widely grown, along with the tea roses, in the second half of last century. They were hardy shrubs with, despite their name, only a limited second flowering in the autumn in most varieties. Famous Hybrid Perpetual varieties include Général Jacqueminot, La Reine, and Frau Karl Druschki.

The Tea and Hybrid Perpetual classes therefore each had rather serious limitations, and it was



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FIGURE 1 – Rosa gallica rosea (*flore simplici*). *From* Les Roses, *by P. J. Redouté, text by C. A. Thory. Folio edition. Published by Firmin Didot, Paris,* 1817–24. *Vol.* 3. (*Original plate slightly larger.*)



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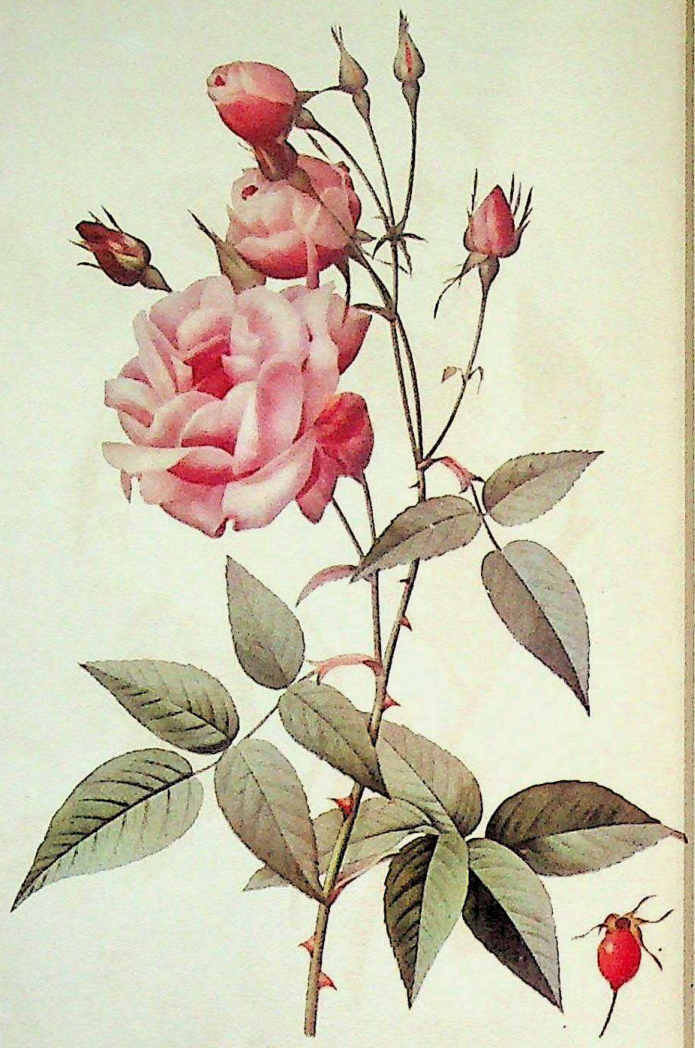

FIGURE 2 – Rosa indica vulgaris. *From* Les Roses, *by P. J. Redouté. Vol.* 1. (*Original plate approximately twice this size.*)

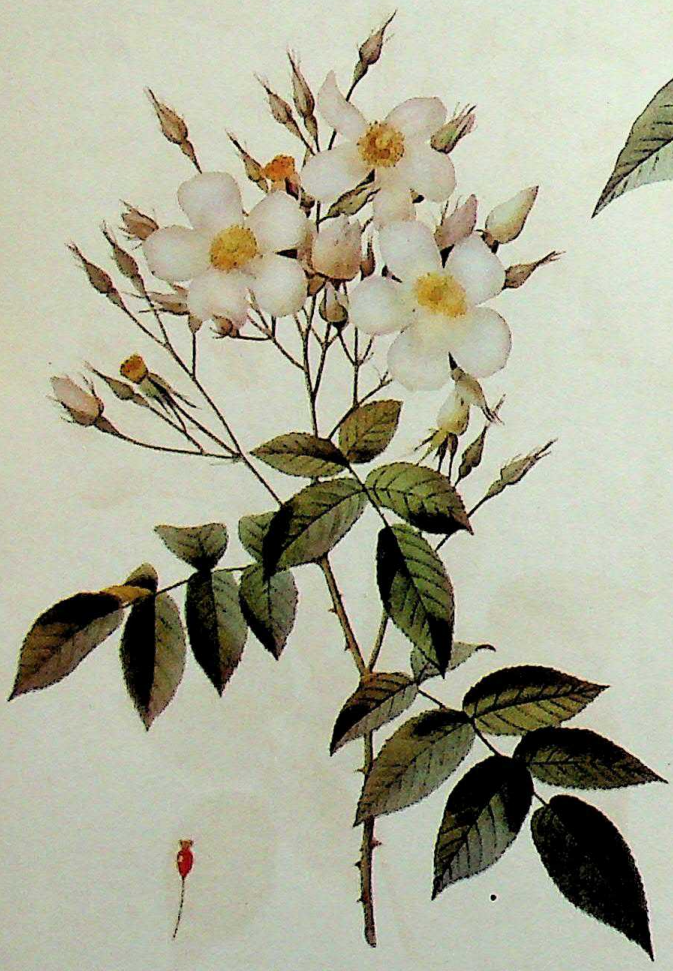

FIGURE 3 – Rosa moschata. *From* Les Roses, *by P. J. Redouté. Vol.* 1. (*Original plate approximately twice this size.*)



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FIGURE 4 – Rosa gigantea (*original painting*). *From* The Genus Rosa, *by Ellen Willmott, F.L.S., drawings by Alfred Parsons, R.A. Vol.* 1, *Plate* 34. *Published by John Murray, London,* 1914. (*Original plate approximately twice this size.*)

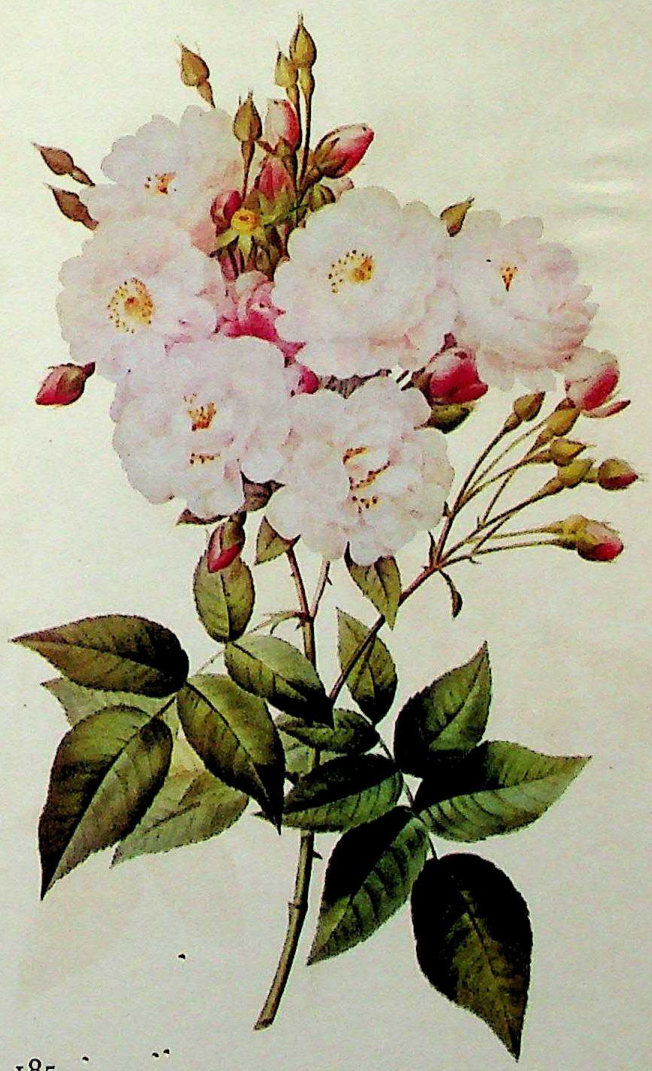

FIGURE 5 – Rosa Noisettiana. *From* Les Roses, *by P. J. Redouté. Vol.* 2. (*Original plate approximately twice this size.*)



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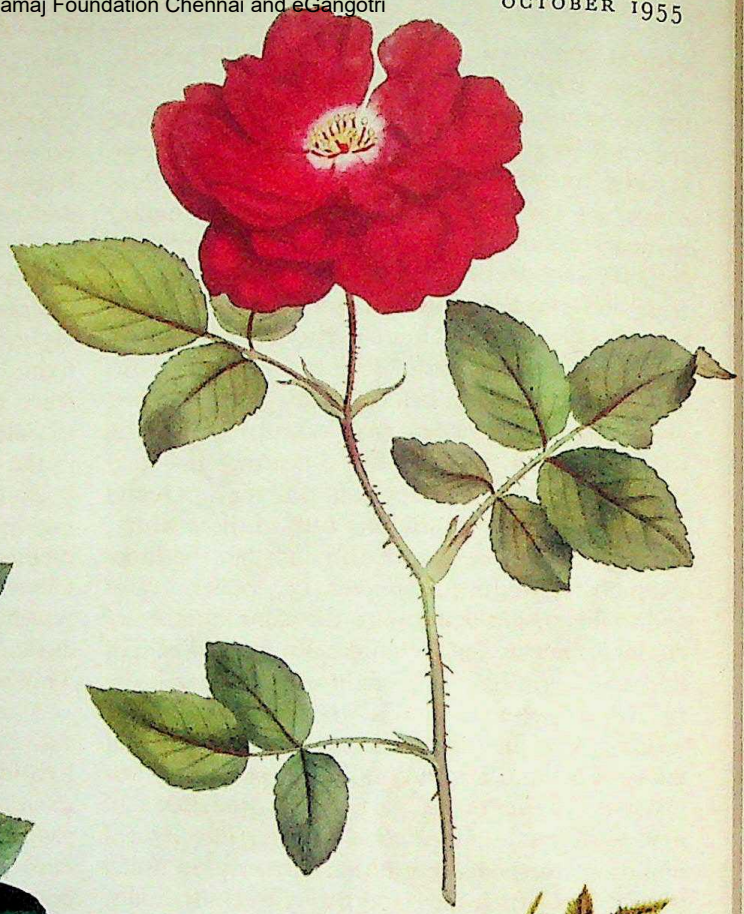

FIGURE 7 (*right*) – Rosa semperflorens. *From* The Botanical Magazine, *by William Curtis*. 1794. *Vol.* 8, *Plate* 284. (*Original plate approximately same size.*)

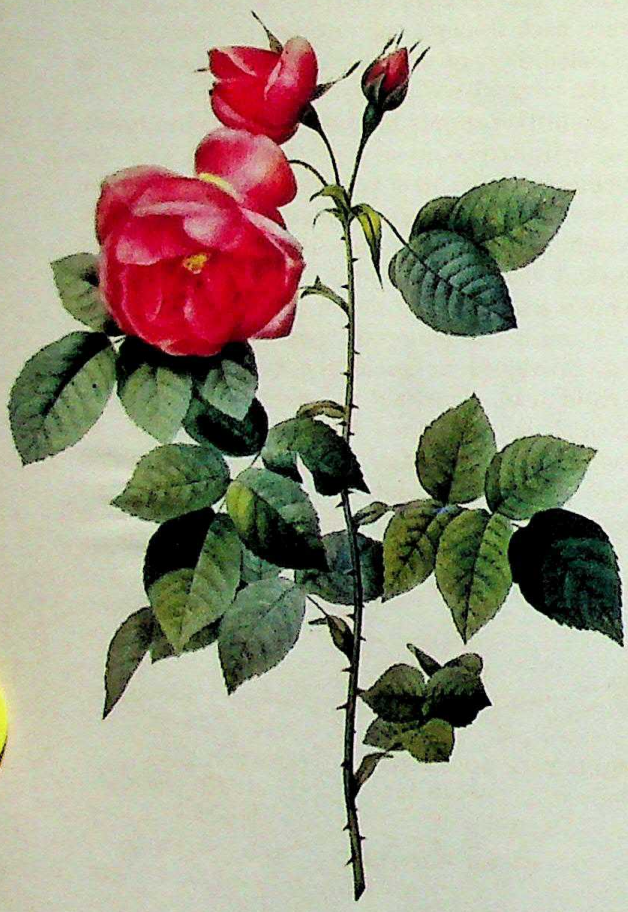

FIGURE 6 (*above*) – Rosa canina Bourboniana. *From* Les Roses, *by P. J. Redouté. Vol.* 3. (*Original plate approximately twice this size.*)

FIGURE 8 (*right*) – Rosa lutea. *Single yellow rose. From* A Collection of Roses, *by Miss M. Lawrance*. 1799. *Published by herself. Plate* 12. (*Original plate approximately twice this size.*)



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natural that attempts should be made to obtain, through hybridization, a race which combined the good qualities of the two. This was first achieved by the French breeder M. Guillot, who in 1867 introduced the variety La France, forerunner of the Hybrid Tea class, the dominant garden roses of this century. La France itself is a triploid, as is to be expected for the product of a cross between a diploid tea rose and a tetraploid hybrid perpetual. These early triploid hybrid teas were rather sterile, like the first Bourbons and hybrid Chinas before them. For the first twenty-five years or so, new hybrid tea varieties were obtained mainly by repeating the tea/hybrid perpetual cross using different parental varieties. Then, towards the turn of the century, tetraploids appeared, probably through the functioning of unreduced gametes, i.e., pollen grains and embryo sacs containing the same number of chromosomes as the somatic cells, instead of half that number. This is brought about through the failure of one or other of the two divisions of meiosis. One of the first tetraploids was the well known Caroline Testout, and in these fertility was restored. A period of very rapid production of new varieties followed as a result. The hybrid teas soon usurped the position formerly occupied in gardens by their ancestors the hybrid perpetuals, largely on account of their more continuous flowering season. Their great advantage over their other ancestors, the tea roses, lay in their comparative hardiness.

The colours of the early hybrid tea varieties ranged from deep red, through pink, to white. There were no good yellow varieties. The development of these had to wait on the introduction of a new species into the garden roses. This occurred at the beginning of this century when M. Pernet-Ducher, the famous French breeder, obtained a hybrid between the Persian yellow rose *R. foetida* (formerly *R. lutea*, see figure 8) and one of the hybrid perpetuals. *R. foetida* is a tetraploid like the hybrid perpetuals and the later hybrid teas. It flowers only once, in early summer, like most rose species. The original hybrid when crossed with a hybrid tea produced the first really yellow variety, Soleil d'Or, from which came the so-called Pernetianas. These were characterized not only by their brilliant yellow and orange colours but also, unfortunately, by lack of fragrance, susceptibility to the fungal disease black spot, and the excessive thorniness of their *R. foetida* ancestor. Repeated crossing with good hybrid tea varieties, and careful selection during the next twenty-five years, led, however, to the elimination of most of the faults brought in by *R. foetida* and also to the complete merging of the Pernetianas with the Hybrid Tea class proper. There are very few hybrid tea varieties bred today which do not trace back through one or other of their parents to Soleil d'Or or one of the other early products of the cross with *R. foetida*.

No further species have been involved in breeding hybrid teas up to the present, so that the members of this now very large group have the following species as ancestors: *R. chinensis*, *R. gigantea*, *R. moschata* (diploids), *R. gallica*, and its ancient derivatives, and *R. foetida* (tetraploids). This is schematically shown in figure 9.

A much less important group of garden roses was developed at about the same time as the hybrid teas. This had its origin in crossing *R. chinensis* with another Far Eastern species, *R. multiflora*, which is a diploid climber with enormous clusters of small, white flowers. In the second generation dwarf plants appeared which produced clusters of flowers all the summer, and from these ancestral varieties, Mignonette and Paquerette,

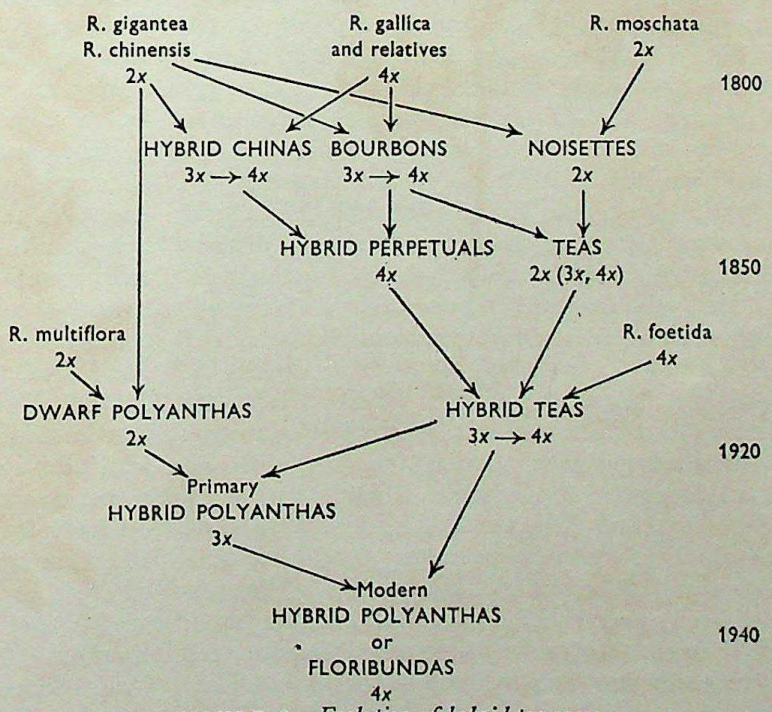


FIGURE 9 – *Evolution of hybrid tea roses*



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was developed the Dwarf Polyantha class (*R. multiflora* at that time being known as *R. polyantha*). Later varieties include Orleans Rose, Gloria Mundi, and Coral Cluster. The Dwarf Polyanthas are all diploids, like their ancestral species. Many varieties in this group have arisen by bud mutation, one of which deserves mention, since it made possible a considerable extension of the colour range in the garden roses. It determined the production of the anthocyanidin pigment pelargonidin in place of cyanidin, the usual pigment in *Rosa* (see Robinson [3] for an account of the anthocyanins and anthoxanthins). Pelargonidin is responsible for the brilliant orange colour of the dwarf polyantha variety Paul Crampel and several others, a colour unknown in garden roses before about 1930.

The Danish breeder Poulsen created a further class by crossing these diploid dwarf polyanthas with the tetraploid hybrid teas in an endeavour to produce a race of really hardy roses with large flowers, suitable for outdoor cultivation in the rigorous climate of northern Europe. In this he was brilliantly successful. The new Hybrid Polyantha class which came into being about 1920 combined the hardiness, long flowering period, and cluster-flowered habit of the dwarf polyanthas with the larger flower size and more elegant shape of the hybrid tea. The early varieties, such as Else Poulsen, are triploids and rather sterile. However, the tetraploid level was regained following back-crosses to the hybrid tea side of the pedigree. Examples are Donald Prior, Dainty Maid, and Maid of Honour (syn. Schleswig). Continued back-crossing has resulted in the production of a number of varieties in the past few years which it is difficult to place in either the Hybrid Tea or the Hybrid Polyantha class, and it seems probable that these formerly distinct classes will merge completely in the next decade.

The primary hybrid polyantha varieties are almost scentless, and rather susceptible to mildew, undesirable characters both inherited from *R. multiflora*. However, the more recent varieties are improved in these respects, particularly the roses in whose origin derivatives of the musk rose and the sweet briar have played a part. Kordes in Germany, and Boerner in America, have been responsible for most of the recent developments in this group. The varieties Independence (Sondermeldung) and Fashion are notable examples of their work: the former for its vivid cinnabar-red colour (due in part to the presence of pelargonidin) and the latter for its delicate coral-peach shade.

There are many other groups of garden roses of lesser importance, some of which deserve to be mentioned briefly (a more detailed account may be found elsewhere [4]). Climbing roses are of a number of distinct types. The Noisettes and climbing tea roses have been noted above. Towards the end of last century hybrids between *R. multiflora* and China roses, Noisettes, and other groups gave rise to the class of Multiflora ramblers which includes Tausendschön and Veilchenblau, with its near-purple flowers. However, a superior group of climbers came from the use of a new species, *R. wichuraiana* from Eastern Asia. Its hybrids have a longer flowering period than do the Multiflora ramblers and are much less susceptible to mildew than the latter. Widely grown varieties include Albertine, Emily Gray, Paul's Scarlet, and Chaplin's Pink. The other important group of climbers consists of climbing sports of the ordinary bush hybrid tea varieties. These are identical with the parent bush variety except in the climbing habit. Unlike the Multiflora and most Wichuraiana varieties which flower for a few weeks only, the climbing hybrid teas produce a succession of flowers throughout the season. Climbing Crimson Glory and Climbing Mrs. Sam McGredy are two of the most reliable varieties, many of which are prone to revert to the bush habit.

There are a number of distinct types of shrub roses which deserve to be more widely grown. One group contains the hybrids of *R. rugosa*. They are very hardy, remarkably resistant to disease, and have a prolonged flowering season. Commonly grown varieties include Belle Poitevine, Roseraie de l'Hay, and Conrad Ferdinand Meyer. *R. rugosa* belongs to quite a different section of the genus from the other ancestral species, and Rugosa hybrids are extremely sterile. This has proved a barrier to further breeding work, which has only recently been overcome through the spontaneous occurrence of chromosome doubling in the diploid Max Graf. The tetraploid so formed, known as *R. kordesii*, is fertile, and the German breeder Kordes has recently produced hybrids from it which approach closely the ideal of a hardy, perpetual-flowering climber.

The hybrid musk roses are excellent shrubs. They are a development from the old Noisettes, through crossing with hybrid teas and other groups, and are largely the result of the work of Lambert in Germany and of Pemberton in England. Some well known varieties are Penelope, Prosperity, and Nur Mahal. They produce



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clusters of sweetly scented flowers all through the summer and autumn. Some hybrid musks have been important in the development of hybrid polyantha-like roses, and many modern cluster-flowered varieties are complex derivatives of combined hybrid polyantha, hybrid musk, and, in some instances, hybrid sweetbriar origin. Examples are Grandmaster, Rudolph Timm, and Cocorico.

The native sweetbriar, *R. rubiginosa*, is one ancestor of the Penzance Briars, produced at the end of last century by Lord Penzance from crosses with the hybrid perpetuals and *R. foetida*. Many were named after Scott's heroines, such as Lucy Ashton, Flora McIvor, and Anne of Geierstein. They retain the sweetly scented foliage of *R. rubiginosa* and have semi-double bright flowers and attractive hips. Derivatives of the Penzance Briars have recently been used by Kordes in breeding cluster-flowered roses, and some of these are notably resistant to the fungal disease black spot.

A final group of shrub roses that may be mentioned has the Scotch or Burnet rose, *R. spinosissima*, as an ancestor. This recent development also is due to Kordes, who crossed the species with hybrid teas and obtained several early flowering shrub roses of considerable merit. These include Frühlingsgold, with double yellow flowers, and Frühlingsmorgen, with large single flowers whose petals are yellow at the centre shading to a vivid pink at the edges.

This brief survey shows that the most important factor concerned in the evolution of the cultivated roses has been interspecific hybridization and, more recently, hybridization between the different groups formed by the earlier crosses. Polyploidy has been significant in some classes in raising initially diploid and triploid members of a group to the tetraploid level of some of their ancestral species. This has undoubtedly facilitated gene exchange in this century between the different rose groups and has led to the disappearance of the boundaries between formerly distinct classes.

Although the genus *Rosa* is a very large and diverse one, with over one hundred species in the North Temperate zones of both New and Old Worlds, only six of these have been used in the development of the important rose groups discussed in this article. A further eight have been concerned in minor developments, some of which have been briefly considered. The remaining ninety per cent of the genus contains many desirable species which have much to offer the breeder of garden roses, as inspection of the National Rose Species Collection at the John Innes Horticultural Institution will show. Fortunately, enterprising breeders on the Continent and in the United States have been using some of these neglected species in their programmes with, in some cases, very promising preliminary results. But there are many problems of sterility to be overcome and much basic genetical information yet to be acquired.

ACKNOWLEDGMENT

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# Problems of phyllotaxis and leaf determination

R. SNOW

The study of the disposition of leaves on the stem is not only of intrinsic interest, but may well throw light on the fundamental problem of what causes leaf formation. Inferences made from observations of already elongated shoots can be misleading. In this article the problems of phyllotaxis are discussed on the basis of observation of exposed stem apices and transverse sections of buds, in which the relative positions of young leaves are still almost unchanged and can be fairly accurately measured, and of operations on stem apices.

Leaves arise as rudiments or primordia, round or nearly so, from the surface of a narrow zone forming a ring just below the summit of the bare stem apex (figure 1). The stem apex is commonly paraboloidal, steeper in some species and flatter in others, but the zone from which the leaves arise approximates to part of the surface of a cone. The leaves arise nearly always in regular positions, so that they form regular patterns, simple in some species and complicated in others. Clearly one problem is what causes a leaf to arise at all; a similar problem is posed by the outgrowth of lateral branches from various filamentous algae and fungi. But a second problem is what causes leaves to arise in regular positions around the apex, since these positions, when first determined, do not correspond to any obvious differentiations within the apex. In this respect the origin of leaves differs from that of lateral roots, which originate below the surface just externally to the first-formed xylem strands. It has, indeed, been suggested that the positions of the leaves depend on those of the conducting strands supplying them, or of some invisible precursors of those strands, but the experimental evidence excludes this in the species tested [1]. The problem of the causes determining the position of the leaves is a challenge, since the regularity of their positions must, like any other facts of differentiation, have a rational explanation. But the study of the location of leaves may also prove to be a useful, though indirect, way of approaching the fundamental question of what causes them to originate at all.

The positions in which the leaves are formed at the apex are the primary factor determining the positions which they later occupy along the main stem, but during the elongation of the stem their relative positions are often changed in various ways. These secondary changes have their own interest, but they present problems quite separate from that of the positions in which the leaves are formed. Nevertheless, the study of phyllotaxis was at first based on observations made on elongated shoots; even now the positions in which leaves have arisen are sometimes inferred from observations of this kind. But such inferences are extremely unreliable, because of the changes that take place during the elongation. In the present paper the problems of the determination and primary location of leaves will be discussed on the basis of observations and experiments made directly on exposed stem apices, and of observations of transverse sections of buds, in which the angular positions of the young leaves can be measured fairly accurately and have not yet changed appreciably.

There are many interesting kinds of phyllotaxis, but here we shall discuss only the commonest kind, the spiral, which raises probably the most interesting questions of all. Two other common kinds will, however, need to be mentioned. One of these is the distichous or two-ranked system (figure 2); this is well known in grasses and in some common *Leguminosae*, including peas and beans. In this system each leaf arises singly and at an angle of 180° from the previous one, so that the leaves form two opposite ranks, which appear radial in bud sections and vertical on the elongated shoot. The other kind is the decussate, or crossed, system (figure 3), found for example in ash, horse-chestnut, and *Labiatae*. In this the leaves arise two at a time, the members of each pair being opposite and in a plane at right angles to that of the previous pair, so that the leaves form four radial or vertical ranks.

Spiral phyllotaxis is found in most flowering



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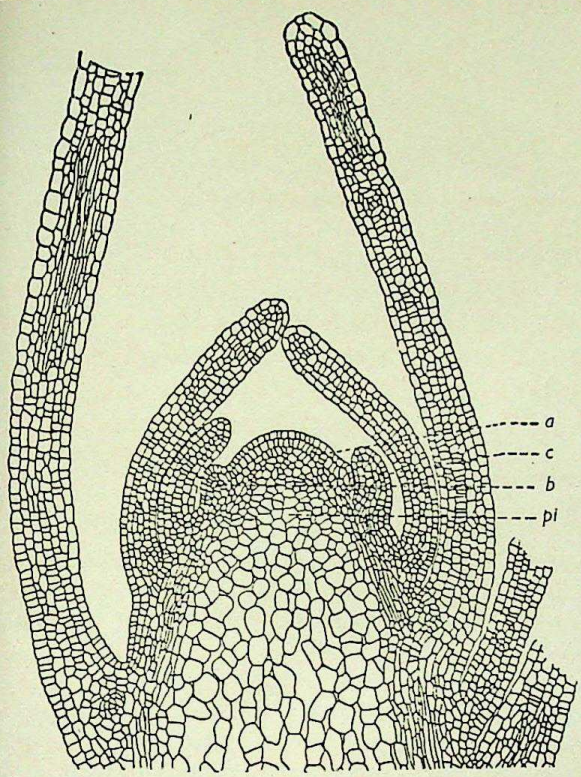


FIGURE 1 – *Median longisection of the stem tip of* Linum, *showing several stages in the ontogeny of the leaf:* a, *section of a very young leaf primordium;* b *and* c, *older primordia, showing early development of provascular strands;* pi, *pith.* (*After Crooks,* 1933.)

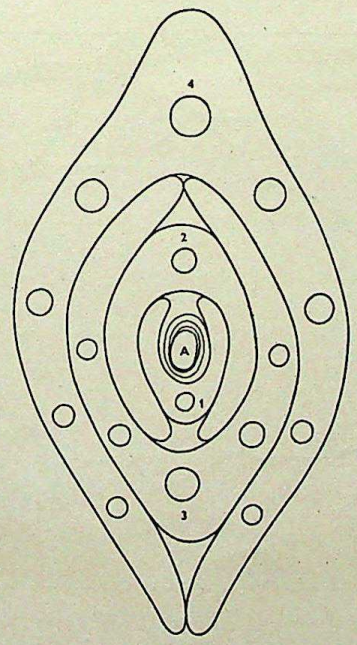


FIGURE 2 – *Transection of distichous apical bud of* Bupleurum perfoliatum. A, *apex;* 1–4, *successive leaves.* (*After van Iterson.*) (× 127)

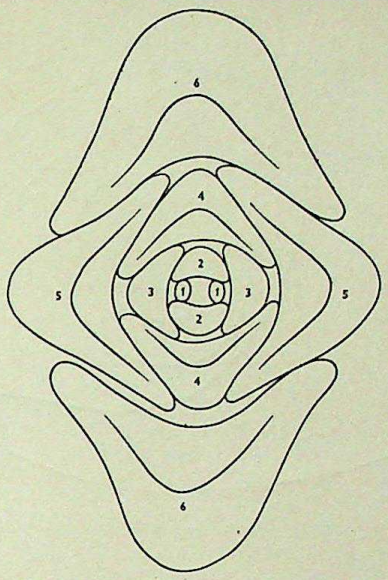


FIGURE 3 – *Transection of decussate apical bud of* Syringa vulgaris. 1, 1 *and* 2, 2, *etc., successive pairs of leaves.* (*After van Iterson.*) (× 45)

plants and conifers, in most ferns, in many lycopods, and in most mosses, though in mosses it is of rather a special kind. The common property of the spiral systems is that a single spiral, called the ontogenetic or genetic spiral, can be drawn through the centres of all the leaves in their order of succession, and that the angles between successive leaf centres are as a rule very nearly constant.

An obvious difference between various spiral systems, and one useful for classification, is that in some the buds contain a small number of relatively large leaves around the apex, and in others a larger number of relatively small leaves (figures 4–6). The former condition is called 'low', and the latter 'high', phyllotaxis. One way of expressing this difference precisely is to count in transections of buds the numbers of certain curves—called the parastichies, or contact parastichies—which are formed by adjacent leaf-bases. There are usually two sets of these curves winding in opposite directions round the apex; they can be seen in figures 4–6, especially clearly in figure 6. In some species there are three sets of such curves (figures 9 and 10).

It is found that the numbers of contact parastichy curves in the two or three sets are nearly always successive terms of the summation series 1, 2, 3, 5, 8, 13; this is the Fibonacci series, in which each term after the first two equals the sum of the previous two. Thus T. Fujita [2], examining vegetative buds of 435 species of angiosperms and 45 of gymnosperms with spiral



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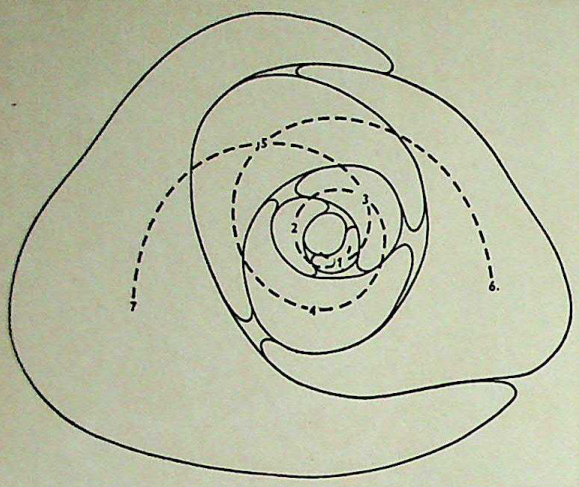

FIGURE 4 – *Transection of apical bud of* Bellis perennis. *Parastichy or contact numbers* 1 *and* 2. *The single parastichy curve is drawn, and one curve of the set of two. Both curves start at leaf* 1. (*After van Iterson.*) (× 36)

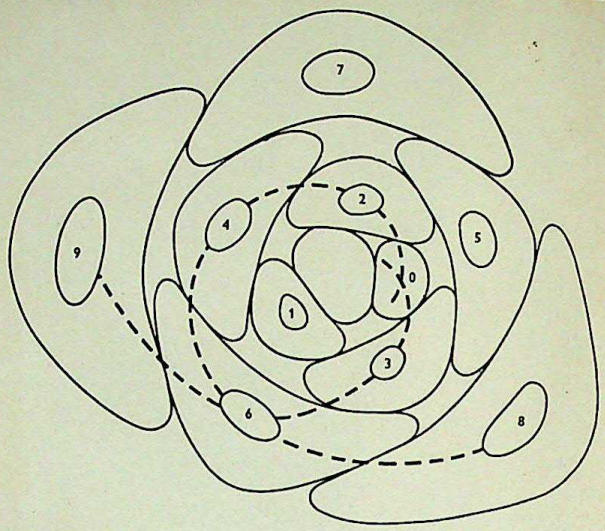

FIGURE 5 – *Transection of apical bud of* Jasminum fruticans. *Parastichy or contact numbers* 2 *and* 3. *One parastichy curve of each set is drawn, starting at leaf O.* (*After van Iterson.*) (× 103)

phyllotaxis, found Fibonacci parastichy numbers in all except one angiosperm and one gymnosperm. The commonest pairs of numbers were 2:3 and 3:5. In the lowest spiral phyllotaxis one parastichy set contains only one curve, which is then the same as the ontogenetic spiral (figure 4). Some of the highest Fibonacci numbers of parastichies are found in the large, flat inflorescences of sunflowers. Figure 7, from A. H. Church [3], shows one with parastichies 55 and 89, and Church has also shown another with parastichies 89 and 144.

Even when the parastichy numbers do not follow the Fibonacci series they regularly belong to some other summation series, usually to the subsidiary series 1, 3, 4, 7, 11, etc. (figures 8 and 9). Examples of still other summation series are known, for instance 1, 4, 5, 9, etc., and 2, 5, 7, 12, etc. [4]. These remarkable facts call for explanation.

In practice, it is often more convenient to find these numbers in a way slightly different from that previously described. One numbers successive leaves in a bud section along the ontogenetic spiral, and then counts how many intervals, or plastochrons, have intervened between the formation of any leaf of the top cycle, and of the two or three adjacent leaves below it. These numbers are called the contact numbers, or contacts, since in flowering plants (though not in ferns) the bases of adjacent leaves are nearly always in contact in the bud. They are the same as the parastichy numbers where there are enough leaves to form parastichies, and they can be found even when there are not. Another way of classifying spiral systems according to their lowness or highness, less simple but more finely graded, has been proposed by F. J. Richards [5, 6]. The higher Fibonacci spiral systems are developed gradually from very low systems. The simplest developments are found in the seedlings of dicotyledons, and examples will be described and discussed later.

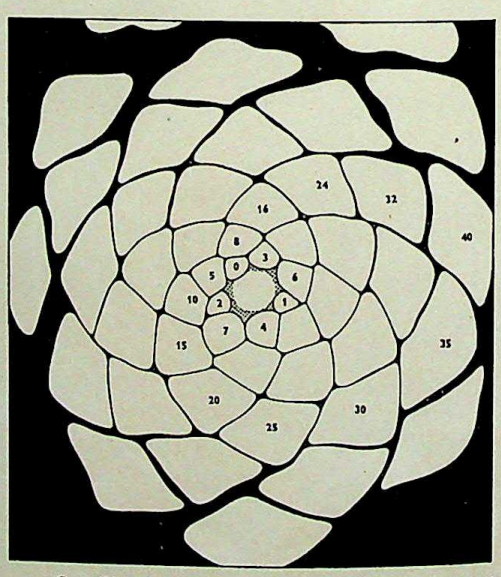

FIGURE 6 – *Transection of apical bud of young seedling of* Pinus pinea. *Parastichy or contact numbers* 5 *and* 8. *The youngest* 8 *leaves are numbered, and also those along one parastichy of each set, starting at leaf O.* (*After Church,* 1920.)



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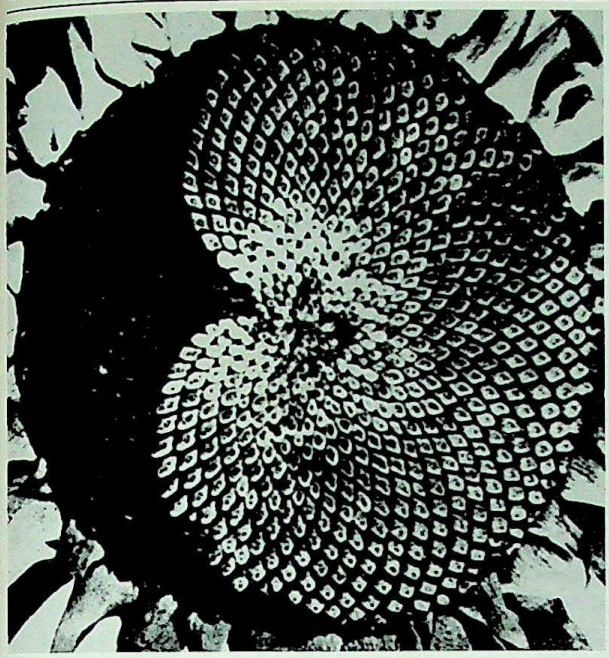

FIGURE 7 – Helianthus annuus. *Capitulum selected as a type. Contact-parastichies* (34 + 55)*; fruits partially removed to show the direction of the curves.* (*After Church*, 1901.)

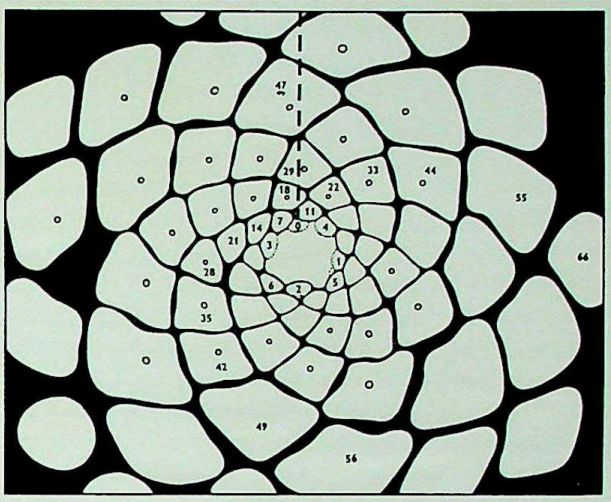

FIGURE 8 – *Terminal bud of branch of* Araucaria excelsa. *Parastichy or contact numbers* 7 *and* 11. *The leaves are numbered along one parastichy of each set. The line drawn outwards from leaf O is explained in the text.* (*After Church*, 1920.)

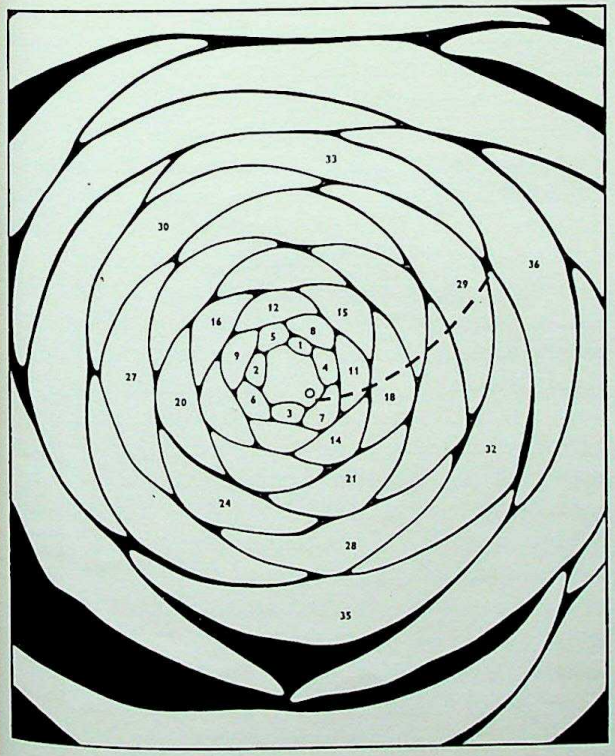

FIGURE 9 – *Apical bud of* Euphorbia biglaendulosa. *Parastichy or contact numbers* 3, 4, *and* 7. *The leaves are numbered along one parastichy of each set. The curved line is explained in the text.* (*After Church*, 1901.)

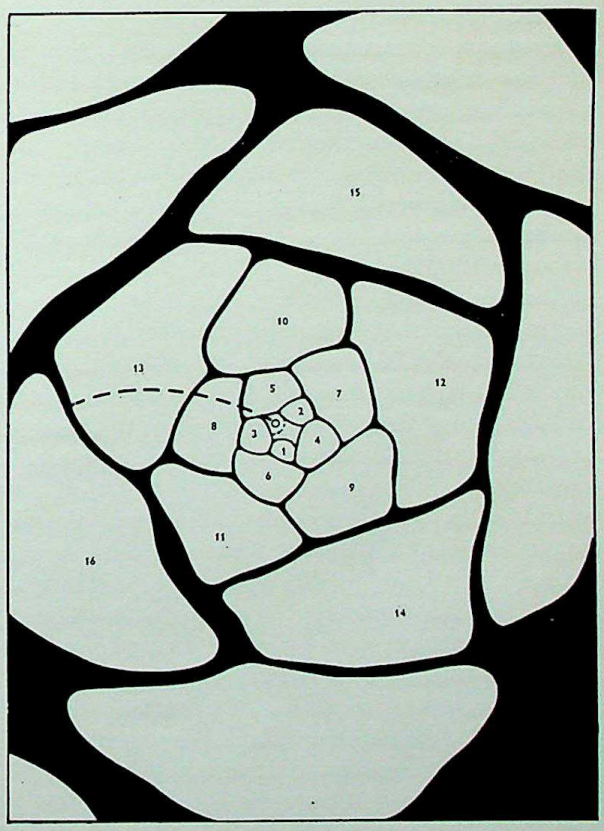

FIGURE 10 – *Apical bud of* Sedum acre. *Parastichy or contact numbers* 2, 3, and 5. *The curved line is explained in the text.* (*After Church*, 1901.)



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DIVERGENCE ANGLES

Study of the divergence angles between successive leaves in spiral systems has revealed equally remarkable facts, but in this connection it is necessary first to consider the famous theory of Schimper and Braun [7], which unfortunately has obscured the truth for 120 years. These authors proposed the rule that the divergence angles are normally rational fractions of 360° and that, while in distichous phyllotaxis the divergence is $\frac{1}{2}$, in spiral phyllotaxis the fractional divergence is usually some later member of the series $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, etc. From this it would follow that one leaf can be found exactly above another, or with its centre on the same radius as seen in bud sections, after a number of divergence angles along the spiral equal to the denominator of the appropriate fraction. Unfortunately they did not measure the angles in bud sections near the apex, but on mature shoots, where it is very difficult to measure accurately and where the original angles have often changed. They found what they supposed to be exactly superposed leaves, and calculated the mean value of the intervening divergence angles.

However, measurements of these angles in sections of buds with Fibonacci spirals do not support the proposed rule in any way. The angles do not fall into groups corresponding even approximately with the Schimper-Braun fractions. Indeed they do not fall into any groups whatever, but in these spirals are very close to the Fibonacci angle itself. This angle, 137° 30′ approximately, is that subtended by a fraction of the circumference equal to the limiting value to which tend the fractions of the Schimper-Braun series. This value differs very definitely from the Schimper-Braun values $\frac{1}{3}$ or 120°, $\frac{2}{5}$ or 144°, $\frac{3}{8}$ or 135°, though the later values of this series of fractions approach it closely.

This is shown most clearly in another valuable paper by Fujita [8], who measured numerous divergence angles, to the nearest degree, in bud sections of thirty species of flowering plants having various Fibonacci parastichy numbers; he usually measured from 100 to 500 angles in each species. He recorded the frequency distributions of these angles. The distributions for all the species have sharp peaks, the maxima at either 137° or 138°. In one conifer having parastichies 3 and 4, belonging to the series 1, 3, 4, 7, etc., the peak of the frequency distribution was at 100°; in the bud of *Araucaria excelsa* (Church [14]), shown in figure 8, the mean of forty-seven angles is 99·8°. Both these values are very close to 99° 30′, the limiting angle of the corresponding series of fractions. In another conifer having parastichies 2 and 5, belonging to the still rarer series 2, 5, 7, 12, etc., Fujita [4] found the peak of the distribution at 151°, again very close to the limiting value 151° 8′.

From these striking results it follows that in spiral systems the leaves commonly considered to be superposed are not really so. It can, indeed, easily be seen in transections of spiral buds that lines drawn through the centres of such leaves, lines forming the so-called orthostichies, are not straight but have a slight and regular curvature in the same direction. This is the easiest way of verifying that in buds the actual divergence angles depart systematically from the Schimper-Braun fractions. The only known exceptions are various succulent species, in which, when the stems develop vertical ridges, the ridges continue up into the stem apex, and then apparently promote the formation of leaves which are formed along them [9]. Fibonacci spirals cannot be classified according to their divergence angles, since these angles are practically the same in all of them, apart from special cases.

However, some observers have stated that in the mature shoots of some, though by no means all, species, the orthostichies are more nearly straight than in the bud, or even quite straight. Such statements are difficult to verify, but in so far as they are true, the explanation is probably that given by P. Teitz [10]. This is that the conducting strands commonly join up along the orthostichies, which are at first curved, being really helices. Later, however, the strands tend to elongate less rapidly than the rest of the stem, and so set up a resistance and get pulled more nearly straight, thereby twisting the whole stem, straightening the orthostichies, and causing the angles on the mature stem to approach the Schimper-Braun values. Such secondary changes are irrelevant to the problem of the primary location of leaves.

Although Fujita's measurements of divergence angles are the most numerous, several earlier workers had also published measurements of divergence angles and other evidence showing that the angles do not conform to the Schimper-Braun rule. The brothers L. and R. Bravais [11] maintained this very convincingly as early as 1837, and so also, more recently, did Church [3] and M. Hirmer [12, 13]. The Bravais, Hirmer, and Church [14] found further that the actual angles are close to the limiting value of the series, even



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though the Bravais made their observations on mature shoots. Yet even now the Schimper-Braun fractional divergence angles are often quoted in discussions of phyllotaxis in buds, as if they were genuine.

### THEORIES OF LEAF DETERMINATION

In attempting to interpret the main facts so far recorded, one needs some theory of leaf determination as a working hypothesis. Such theories can be tested for their agreement both with observations of naturally growing plants and with the experimental results now available from operations upon stem apices or the youngest leaf primordia. Only a few theories will be discussed here, and mainly those that are attracting interest at present.

Schimper and Braun supposed that some leaf-forming impulse moved along the ontogenetic spiral, but there is plenty of evidence that the ontogenetic spiral has in general no causal significance. For instance, in the inflorescence heads of Compositae, one side may cease to grow, so that the ontogenetic spiral is lost, but yet the phyllotaxis may continue fairly regularly on the other side [15]. The spiral can also be reversed experimentally [16, 21].

A very different theory of leaf-forming impulses was put forward by Church [3, 14]. He supposed that such impulses moved centrifugally along two sets of intersecting curves, which wound round the stem apex and were continuous with the leaf-parastichies below. New leaves were supposed to be formed at the intersections of the curves [14].

Another parastichy theory has been proposed recently by L. Plantefol [17, 18], and has found much favour in its country of origin. He supposes that leaf-forming influences travel from below upwards into the leaf-forming zone of the apex along one set of curves, which he calls foliar helices. These curves are the parastichies of one of the two intersecting sets, at least in low phyllotaxis systems of dicotyledons, where they are supposed to be regularly two in number. In higher systems the foliar helices are supposed to branch, and in distichous dicotyledons it is not clear what they are supposed to be. The choice of one set of parastichies only is arbitrary, since there is no valid reason for preferring one of the two intersecting sets to the other. This is especially obvious in the symmetric distichous and decussate systems (figures 2, 3), in which the two sets are alike. The theory would make it very difficult to account for the observed constancy of the divergence angles along the ontogenetic spiral, especially after a change in the number of parastichies, as Richards has clearly explained [6]. For after such a change, the angle between subsequent leaves along each of the foliar helices would need to be changed correspondingly.

The experimental evidence also is against the theory. In many operations made on apices of the common fern by C. W. Wardlaw, and on *Lupinus albus* by M. and R. Snow, two species having Fibonacci spirals, no indication has been found that leaf formation is promoted in the slightest by any influence deriving from existing leaves along either set of parastichies. Yet several of these experiments would have revealed such an influence if it had existed. For example, in the common fern Wardlaw [19] found that the next three leaf primordia due to arise, $I_1$, $I_2$, and $I_3$, were formed normally even when their presumptive areas were confined between two radial cuts which, as his drawings show, quite separated each of them from the older primordia of both of the intersecting parastichies to which it belonged. Further, $I_2$ is not yet determined at the time of operation, as is shown by other experiments by Wardlaw [20].

In *Lupinus albus*, M. and R. Snow [21] made a radial cut through the presumptive area of $I_1$, approximately in its median plane, and extending well below that area. Sometimes a newly determined leaf arose with its side abutting on one side of the wound—the uphill or anodic side in relation to the ontogenetic spiral—and sometimes it arose abutting on the other—the downhill side of the wound. In one or other of these two groups of results this new leaf must have been determined when quite cut off from the older members of its foliar helix, to whichever set of parastichies this may be supposed to belong.

On the other hand, J. E. Loiseau [22] claims to have eliminated a foliar helix in seedlings of *Impatiens roylei*, which have leaves in whorls of three, by pricking one primordium of the youngest whorl to destroy it. In 20 per cent of the seedlings so treated, the number of leaves in each whorl was reduced to two for varying periods after the operation. These results might be due to a reduction of the apical cone, which after the operation was not large enough to give rise to three primordia in a whorl, since in older plants weak normal shoots have only two leaves in a whorl. Microscopic details are needed, but are not given.

However, most theories of leaf determination are based on W. Hofmeister's deservedly famous



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rule [23] that each new leaf arises in the largest gap or depression between the existing leaves or other members surrounding the apex. That this is indeed a general rule has since been fully confirmed by many observers and supported by experiments [16, 20, 21, 24]. There do admittedly appear to be some exceptions, for instance in whorl-forming plants after a disturbance [25], but in these some additional factor appears to be at work. The causes underlying Hofmeister's rule have been sought mainly along two rather different lines. In one group of theories it is supposed that the new leaf arises where it does because influences inhibiting or repelling the process of leaf determination spread out both from the summit of the apex and from the centres of the existing leaf-primordia. It is further supposed that the morphological centre of a new leaf is determined first and then the rest of the leaf-base forms around it. In another theory it is supposed that a definite minimum free area of the apical cone at a minimum distance from the summit is needed for the determination of a leaf, and that the necessary free areas become successively available in the depressions between the existing leaves by the continued growth of the whole apical cone. Each leaf is supposed to be determined as a whole over its minimum or primary area. This theory is implicit in the valuable work of G. van Iterson [26] and was supported experimentally and stated in this form by M. and R. Snow [16].

The first of these theories, the repulsion theory, is the more attractive, seeming more physiological and modern, but the writer claims that the second is the one which the experimental evidence supports. It would take too long to argue the case between them at length, and we have done so elsewhere [21]: here only two more recent pieces of evidence will be mentioned. If in *Lupinus albus* and *Euphorbia lathyris* two radial vertical cuts are made in the apical cone so as to confine between them the greater part, but not the whole, of the minimum area presumptive for $I_2$, the next primordium but one due to rise, then no primordium arises between the cuts and the region between them remains bare, though it grows and remains healthy [27]. Yet if the centres of leaf primordia were determined first, then a centre would be determined between the cuts, and would form an imperfect leaf round itself.

Again, in eleven apices of *Lupinus albus* the central part of $P_1$, the youngest actual primordium, was removed or destroyed down to its base [27]. After fourteen days the buds were sectioned and the divergence angles measured. The variations of angle were very small in this series, and the primordia $I_1$, $I_2$, and $I_3$ which arose after the operation were all exactly in their normal angular positions (figure 11). Yet $I_2$ and $I_3$ were not determined at the time of operation [21], and they made contact at their bases with $P_1$, the primordium operated upon. There could hardly be a more direct and simple test of the theory that the youngest primordia repel the subsequent ones, and the answer seems quite clear: in *Lupinus albus* at least they do not do so. These results conflict also with Plantefol's opposite hypothesis of leaf induction by existing leaves.

The criticism that the space-filling theory is bare and formal is now partly met by a recent finding that the minimum area for leaf determination is regulated by the summit of the apex. For it now appears that a minimum area must be reached before this area can overcome an inhibition of leaf determination coming from the summit [28].

However, it would be too much to expect this or any other theory to explain completely all the various kinds of phyllotaxis in all species. In some species other causal factors undoubtedly complicate matters. Also, van Iterson's theory does not apply to species in which the leaf-bases are not circular, though the underlying ideas can be extended to them. Neither does it apply, as it stands, to the ferns, in which the bases of the leaves are not in contact. But in this group there are some indications that each leaf-base surrounds itself soon after it has arisen, with a larger, but sharply limited, area unavailable for other leaves [27]. Similar possibilities need to be considered for any regular phyllotaxis systems in other plant groups in which the leaf-bases may be found not to make contact. Such systems seem to be far from common.

### OUTLINE OF AN INTERPRETATION OF THE MAIN FACTS OF PHYLLOTAXIS

Armed with a working hypothesis of leaf determination, we can try to interpret some of the main facts of phyllotaxis. At the same time we shall be testing the working hypothesis. The questions will be how the Fibonacci spirals are reached in ontogeny, how it is that the parastichy numbers change repeatedly to higher numbers of the Fibonacci or other summation series to which they belong, and how it is that the divergence angles are so close to the limiting angle for the series. It would take too long to do more than indicate the kind of explanation that is possible.



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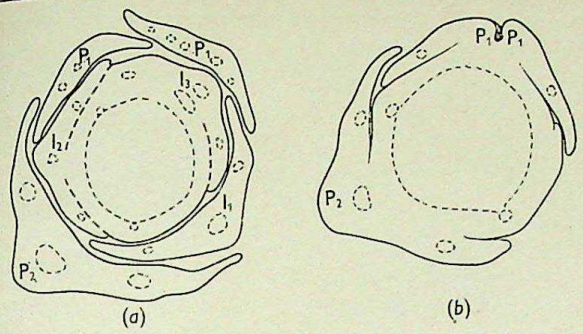


FIGURE 11 – *Transection of apical bud of* Lupinus albus 14 *days after removal of the central part of the youngest leaf-primordium,* $P_1$.

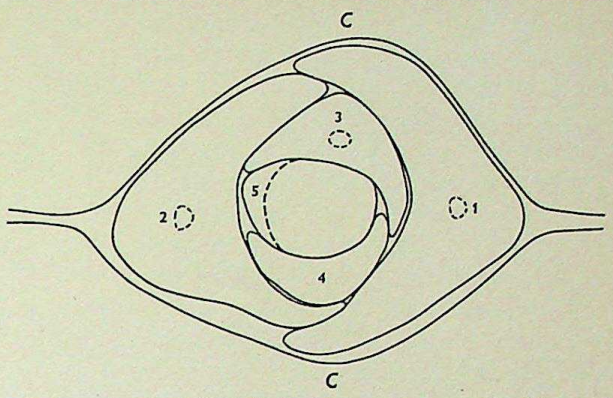


FIGURE 12 – *Apical bud of very young seedling of* Lupinus albus. *The cotyledons are marked* C.

On van Iterson's theory [26] the bases of the young leaves are, apart from special cases, circular when seen from a direction at right angles to the surface in which they are inserted. From these bases the leaves at first grow up vertically, and horizontal sections through their upstanding parts give the familiar crescentic leaf-shapes seen in bud sections. The leaf bases in constant phyllotaxis are considered to form a continually similar system of touching circles. The height of the phyllotaxis, measured by the parastichy or contact numbers, depends on the arc of the circumference covered by each young leaf base. But with some values of these arcs two or more different pairs of numbers, belonging to different summation series, are possible, and the decision between them depends on how the system has developed.

As an example of development we will take the seedling of *Lupinus albus* (figure 12). The opposite cotyledons are followed by two leaves, 1 and 2, in the transverse plane, which are opposite but unequal. Leaf 2 is smaller and inserted higher on the axis than leaf 1, and is therefore younger: it makes contact with leaf 1 on both sides. In order to understand the positions of the leaves, one must remember their circular bases. If each leaf is determined in the first sufficient space that reaches a sufficient distance below the summit, then one may think of its base as if it were a circular plastic disc, partially wrapped round the apical cone and free to slide down the oblique surface under gravity. It is then clear that leaf 2, being wrapped round an arc of more than 180°, must rest symmetrically on the two sides of leaf 1, which also covers more than 180°.

Leaf 3 covers a smaller arc, too small for its base to rest on the two sides of the base of leaf 2. Where, then, is the lowest position for it, the position into which its base may be imagined to sink? Not opposite to leaf 2, since there it would be directly over the median and highest part of the base of leaf 1. Instead, the position which leaf 3 occupies is above one side of leaf 1 and of leaf 2, and rather closer to leaf 1, which is inserted the lower. Thus leaf 3 makes contacts with 1 and 2. Leaf 4 arises above the other sides of leaves 1 and 2, but it cannot arise at the same time as leaf 3, since the nearer side of leaf 3 extends too far round the apex to leave room for another leaf at the same level. So leaf 4 has to wait until it can occupy a slightly higher position rather closer to leaf 2, and with one of its sides above the side of leaf 3. With leaf 4 the spiral sequence has started, and the apex is committed to the Fibonacci series, since leaf 4 makes contacts 1, 2, and 3.

The arcs of the subsequent leaves are not much smaller until just before flowering, and the contacts either continue to be 1, 2, and 3, or more often become 2 and 3 only. The early divergence angles in these young seedlings oscillate, being alternately above and below the Fibonacci angle, to which they gradually approximate. On the same principles, based on space-filling theory, the course of development can be readily explained in many other seedlings, and also in axillary buds and after various operations on stem apices. Indeed, the theory fits so many facts so well that experience in applying it brings increasing confidence.

In many species other than *Lupinus albus* the leaf arcs continue to fall, and the contact numbers to rise up the Fibonacci series. How are these numbers to be explained? Figures 13 and 14 indicate the answer. In figure 13, a transection of a bud of a young shoot of *Sempervivum calcaratum*, it can be seen that the young leaf marked 0, the youngest leaf clearly shown, makes contacts 2 and 3. Let us again imagine, as a model, that the



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circular bases of the young leaves are plastic disks able to slip down the surface of the apical cone, and that this bud goes on growing. If now the subsequent leaves cover smaller arcs, then before long in our imaginary model the leaf corresponding in age to leaf 0 of figure 13 will not rest upon the sides of the leaves that would form contacts 2 and 3, since all these leaves will be too small. Instead, the leaf considered will slip down between those that would form contacts 2 and 3, and will be supported instead on those forming contacts 3 and 5 below. This change may have occurred at the next younger leaf, and the change has certainly occurred in figure 14, a transection of a bud of an older shoot of the same species, where the leaves marked 2 and 3 are resting on contacts 3 and 5. Similarly it can be seen in figure 14 that if the leaf arcs were to diminish still further, the corresponding leaves would slip through the gaps between contacts 3 and 5 and rest on contacts 5 and 8, as the leaf marked 1 has actually done. A still further fall of arc would lead to contacts 8 and 13, and so on. The process is indicated by the straight lines drawn outwards from the centres of the youngest leaves in figures 13 and 14.

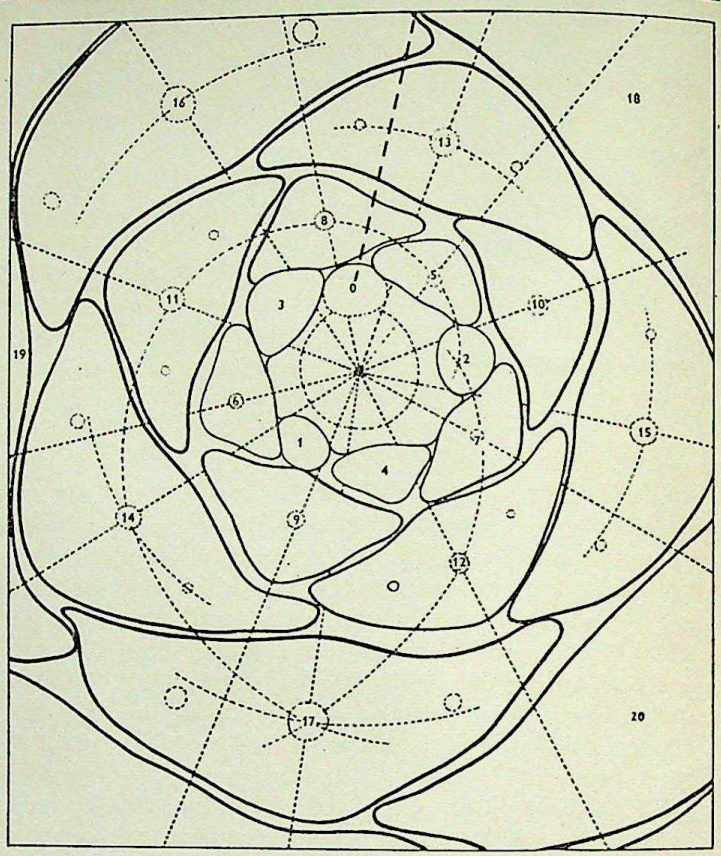


FIGURE 14—*Apical bud of older plant of* Sempervivum calcaratum. (*After Church*, 1920.)

Thus essentially a fall in arc leads from lower to higher contact numbers of the Fibonacci series, because the centres of leaves differing in age by numbers of plastochrons that are successive numbers of the series straddle the same radius, falling alternately on each side of it. This can be verified either on bud sections or in theoretical diagrams, and is discussed geometrically by Richards [5] and several earlier writers. The same holds, indeed, for phyllotaxis systems belonging to any summation series, and an example in another series is indicated by the radius drawn through leaf 0 in figure 8. Thus, whatever the pairs of contacts with which a spiral system starts, the contact numbers will rise up the summation series constructed from the first pair if the leaf arcs diminish sufficiently. The principle underlying this explanation holds good with any theory of determination based on Hofmeister's rule, and Richards [5] has emphasized that as the phyllotaxis rises, the gaps between the leaves become smaller, and so the new leaves will be located more and more accurately. Incidentally, the curious fact may be noted that in buds with threefold contacts the leaves differing in number by successive numbers

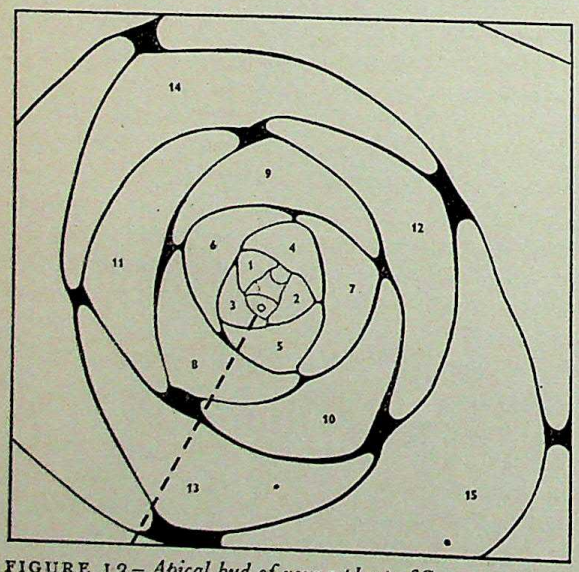


FIGURE 13—*Apical bud of young plant of* Sempervivum calcaratum. (*After Church*, 1901.)



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of the summation series concerned are found often, or perhaps always, to straddle a steep curve, instead of a radius. This is indicated by the curved lines drawn outwards from leaf 0 in figures 9 and 10.

The theory of van Iterson comes near to explaining also the mean values of the divergence angles, but here a difficulty remains. He has shown geometrically that if his basic postulates are granted concerning the shapes of the apex and young primordia, then a regular contact system of primordia with any particular pair of contact numbers must have a divergence angle within a certain range. This range always includes the limiting angle for the summation series to which the contact numbers of the system belong, and it is very narrow when these numbers are moderate or high, for instance 3 and 5 or higher numbers in the Fibonacci series, but wider when the contact numbers are low. On this theory, therefore, one would expect the mean divergence angles to be very close to the limiting angle of the series concerned when the phyllotaxis was fairly high but to vary considerably in different species when it was very low.

But the difficulty is that, even in species with the low contacts 1 and 2, the mean divergence angles are commonly close to the limiting Fibonacci angle when the phyllotaxis is fully established, as was pointed out by van Iterson himself, although on his own theory the range possible for them is large—from 128° 34′ to 180°. Similarly in three species with contacts 1 and 2 studied by Fujita [8], the peaks of the frequency distributions of the divergence angles are at 137° or 138°, and are quite sharp. This difficulty was discussed by van Iterson, who suggested a rather difficult explanation. Another possible line of explanation is the following. A wide range of angles is indeed possible with contacts 1 and 2, but, on van Iterson's theory, within this range every different angle is associated with a different leaf arc. If therefore the Fibonacci angle has perhaps some biological advantage, then natural selection may have brought about a close approach to this angle even in species with contacts 1 and 2, by selecting and fixing genetically the corresponding leaf arc.

Among other problems remaining to be studied are the causes of the stability of phyllotaxis systems when accidentally disturbed, the developments leading to contact numbers belonging to other summation series, and above all the nature of the process by which, on the theory here adopted, each successive available space on the apical cone organizes itself to form a leaf. There are also still several plant groups with special and interesting kinds of phyllotaxis which deserve to be studied specially.

ACKNOWLEDGMENTS

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# Germanium and its uses

J. N. ALDINGTON and H. W. CUMMING

In a recent issue of ENDEAVOUR (13, 101, 1954) K. K. Darrow described the theory of semiconductors and their significance in the physics of the solid state. In the practical application of semiconductors, germanium, an element about which very little was known even fifteen years ago, occupies a place of unique importance. Its preparation on a considerable scale, in the form of virtually pure single crystals, presents many points of interest. Germanium is also finding a further important use as a deep-red phosphor for lamps.

Fifteen years ago, in spite of its wide distribution in the Earth's crust, the element germanium was unfamiliar even to the scientific world and quite unknown to the general public. Today, notwithstanding the difficulties associated with its extraction and purification, it is one of the most important of the rarer elements.

Three developments have lead to this change. The first was the production of a germanium rectifier capable of withstanding high back-voltages; the second was the pioneer research at Bell Telephone Laboratories which lead to the development of a germanium triode, or transistor, capable of amplifying; and the third was the production of germanium compounds which fluoresced in the deep-red region of the spectrum. As a result of these discoveries, and many others stemming from them, interest in germanium has been greatly stimulated: many groups of research workers are studying solid-state physics, and much literature on the subject has been published.

Historically, the discovery of germanium was of considerable scientific interest. In 1871, Mendeléef predicted the existence of a further metal in Group IV; he gave it the name eka-silicon and detailed its principal properties. In 1886 Winkler discovered germanium in the rare mineral argyrodite—a mixed silver-germanium sulphide containing some 7 per cent by weight of germanium—and it was found to have the properties of the element whose existence Mendeléef had predicted.

No massive source of germanium has so far been discovered, even though, in association with other minerals, germanium-containing compounds are present in the Earth's crust to the extent of about one part in 150,000. The major source of the element in Great Britain is flue dust from gas works. Certain British coals contain germanium compounds in small concentrations, and it has been found that it is present to the extent of about 1 per cent by weight in the dust from retorts making producer gas. The method of extraction from the flue dust consists essentially in concentrating the germanium as a copper-iron-germanium alloy and then removing it in the form of its tetrachloride. After purification by fractional distillation, the germanium tetrachloride is decomposed by water, and the resulting dioxide is finally reduced in hydrogen to the metal [1]. The more important physical properties of the element relevant to the present discussions are shown in table I.

Apart from its uses as a red-fluorescing phosphor and as a semiconductor, germanium finds minor applications in dentistry and in the production of glasses capable of transmitting infra-red radiation.

TABLE I

*Principal physical properties of germanium*

| | |
|---|---|
| Atomic weight | 72·6 |
| Electronic structure | 2 8 18 4 |
| Melting-point | 959° C |
| Relative density | 5·47 |
| Electrical resistivity (intrinsic) | 60 ohm cm |
| Electron mobility | 3600 cm²/volt sec |

## GERMANIUM-CONTAINING PHOSPHORS

The high-pressure mercury electric discharge lamp, as opposed to the familiar fluorescent lamp, which has a low-pressure discharge, has become of considerable importance as a light source during the twenty-five years which have elapsed since its development. The disadvantage of its dominant yellow-green radiation has, however, adversely affected its application in circumstances where reasonable colour discrimination is desirable or necessary. Methods for efficiently adding blue and, even more important, red light to the primary mercury radiation have always been regarded as important objectives of research on lamps. Many methods have been tried and some have been adopted, with varying success. A particularly important possibility, recognized even in



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the days of the Cooper-Hewitt lamp, was that of converting some of the ultra-violet radiation into red light by fluorescence. The organic dye rhodamine and some of its derivatives were used for this purpose, but while initially successful they gradually bleached under the ultra-violet irradiation. Lamps containing inorganic sulphide phosphors having red-fluorescing properties have been used for many years; the general method is to coat with the phosphor the inside of an outer bulb containing the mercury lamp. While a useful effect can be obtained, the amount of red light which can be added in this way is far too small to correct fully the deficiencies of the mercury radiation. It is also necessary to use a fairly large outer bulb to carry the phosphor, because the efficiency of the sulphide phosphors rapidly declines at temperatures above about 120° C.

There was thus an urgent need for a phosphor capable of efficient operation at temperatures of several hundred degrees centigrade and notably effective in converting mercury radiation of 2537 Å and 3650 Å wavelength into deep-red light. From the hundreds of possible compounds that were investigated, a magnesium germanate was eventually developed which had the required properties [2]. This germanium compound is now being produced commercially in substantial quantities, and constitutes a new use for the element. Table II compares the spectral distribution of the light from a plain mercury lamp with that from a lamp of the same type but having the colour modulated by a magnesium germanate phosphor; for comparison purposes figures are also given for a typical daylight from a zenith blue sky having an equivalent colour temperature of 13 700° K. The increased radiation is particularly marked in bands 7 and 8; a small increase in the luminosity of these two bands has a marked effect upon the colour-rendering characteristics of the total radiation.

TABLE II

*Percentage spectral luminosities for a plain mercury lamp, for a colour-corrected mercury lamp, and for a typical cold daylight*

| *Waveband (Ångströms)* | *Percentage luminosity* | | |
|---|---|---|---|
| | *Plain mercury* | *Colour-corrected* | *Daylight* |
| 1. 3800–4200 | 0·026 | 0·022 | 0·052 |
| 2. 4200–4400 | 0·67 | 0·54 | 0·38 |
| 3. 4400–4600 | 0·06 | 0·10 | 1·265 |
| 4. 4600–5100 | 0·72 | 0·96 | 13·85 |
| 5. 5100–5600 | 53 | 46·5 | 44·8 |
| 6. 5600–6100 | 44·4 | 46·5 | 31·8 |
| 7. 6100–6600 | 1·0 | 5·0 | 7·4 |
| 8. 6600–7600 | 0·13 | 0·43 | 0·45 |

A more subtle application of a similar germanium compound is as an addition to the fluorescent powder normally used in low-pressure fluorescent tubes. In this type of lamp the discharge occurs in mercury vapour at a very low pressure and the primary radiation is emitted principally at the resonance wavelengths of 1850 Å and 2537 Å. The actual source of visible light is therefore predominantly the fluorescent powder which is coated along the whole of the inner surface of the glass tube in which the discharge takes place. The phosphor most commonly employed today, on account of its stability and high efficiency, consists mainly of a calcium halo-phosphate. Antimony and manganese are present as activators, and by varying the ratio of these two elements in the phosphor the colour of the light emitted can be varied from blue to orange; by suitable choice of the proportion of the activators white light can be produced. The quality of this light has proved acceptable for all commercial applications, and a range of near-white colours is obtainable. In spite of this, research workers in Britain and other European countries and in America have long sought a phosphor capable of producing a higher proportion of deep-red light than has so far proved possible with phosphors of the calcium halo-phosphate group. It has been found that a manganese-activated magnesium germanate has the required properties, and that its addition to suitable calcium halo-phosphates, to the extent of some 10 per cent by weight, permits appreciably better colour-rendering of some of the more difficult hues. Not only is the deep-red colour-rendering of the fluorescent lamp improved, but there is a noticeable reduction in the effect of the 4047 Å and 4358 Å mercury lines, which, although of low intensity, have a high chromatic effect. There are therefore considerable possibilities for germanium phosphors in the further development of fluorescent tubes.

### GERMANIUM AS A SEMICONDUCTOR

Since the development at Purdue University, some fifteen years ago, of a germanium rectifier having improved properties, and the announcement by Bell Telephone Laboratories in 1948 of an amplifying device employing a single crystal of



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germanium, progress in the development of germanium devices has been rapid and entirely new fields of research in the physics of the solid state are being explored. These developments may directly or indirectly affect the whole future of telecommunications, to mention only one important field. For this reason an understanding of the basic principles underlying the production of semiconductor devices is of general interest. The physical properties and characteristics of semiconductors have been discussed recently in this journal [3] and elsewhere [4]. While it should be appreciated that other materials are receiving attention—particularly silicon and the intermetallic compounds of Groups III and V of the Periodic Table—it is nevertheless germanium which has stimulated the greatest interest and which is almost exclusively the material used in the devices available at the present time.

Types of semiconductor devices already developed include polycrystalline, high back-voltage, point-contact rectifiers; monocrystalline junction rectifiers or diodes; single-crystal triodes (for which the term transistor has been coined); single-crystal tetrodes; phototransistors whose electrical resistivity changes with variation in the incident illumination; and power rectifiers capable of handling currents of hundreds of amperes. This short, and by no means exhaustive, list of semiconductor devices indicates the rapid progress already achieved in this comparatively new field. This progress has been made possible by the concentrated effort of many research laboratories following the important possibilities opened up by the pioneer work in the Bell Telephone Laboratories.

### THE TRANSISTOR

The name transistor has been given to a semiconductor device carrying three external electrodes —base, collector, and emitter. Although not strictly analogous, these electrodes may under certain conditions be considered to be roughly equivalent to the cathode, anode, and grid in a thermionic valve. The application of a voltage between base and collector causes a low current to pass, and a change of current between emitter and base produces a proportionately greater change in the current through the collector.

A typical transistor dissipates some hundreds of milliwatts at currents of a few milliamperes. It is an extremely small device in both size and weight, and yet it is robust; there are indications that it may have an almost infinitely long life. Unlike the conventional amplifying valve, the auxiliary power consumption is remarkably small. Crystal devices are potentially suitable for the replacement of all types of valves. Particularly in the fields of guided missiles, telecommunications, electronic computors, and electronics generally, semiconductors are playing an increasingly vital part.

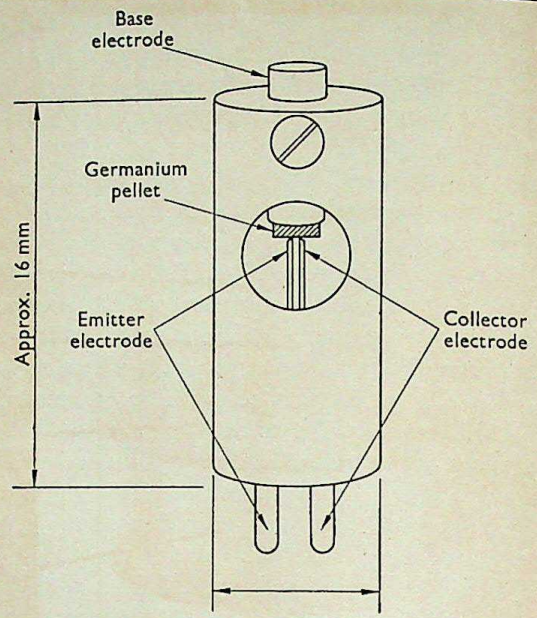


FIGURE 1 – *Diagram of point-contact transistor.*

Transistors are of two main types, commonly termed point-contact [4] and junction. Within the latter group there are three principal divisions, namely grown junction [4], fused junction [5], and surface barrier [6]. It is with the earlier type, the point-contact transistor, that the following description deals. It consists essentially of a base of single-crystal germanium on the surface of which are placed, very close together, pointed wires of phosphor bronze and copper-beryllium; these form respectively emitter and collector. The system may be assembled for convenience in the form shown in figure 1. Further constructional details will be given later in the section dealing with transistor assembly.

### PREPARATION OF GERMANIUM SINGLE CRYSTALS

Very pure germanium dioxide is first prepared by ordinary chemical methods [1]; the arsenic content in particular must be reduced to less than 0·05 part per million. The germanium dioxide, contained in special graphite boats, is then reduced in hydrogen to the metal. When reduction is complete, the germanium is fused into an ingot some 9 × 1·5 × 0·75 cm.



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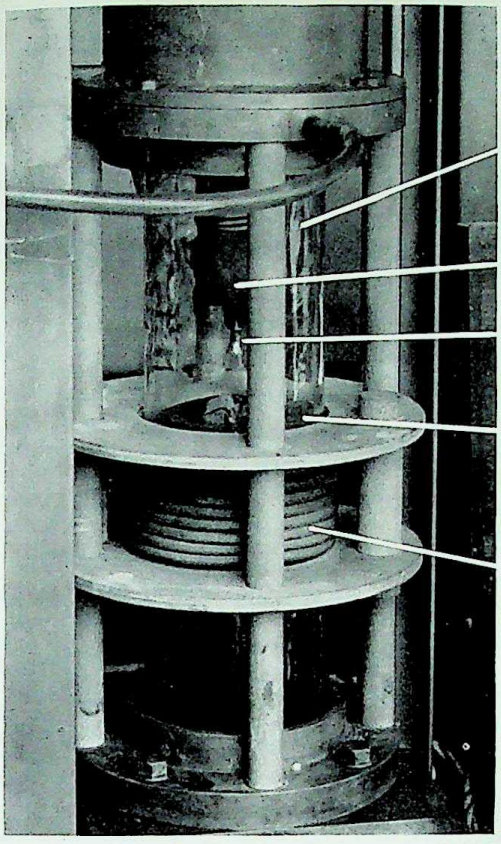


FIGURE 2 – *Apparatus for growing large single crystals of germanium.*

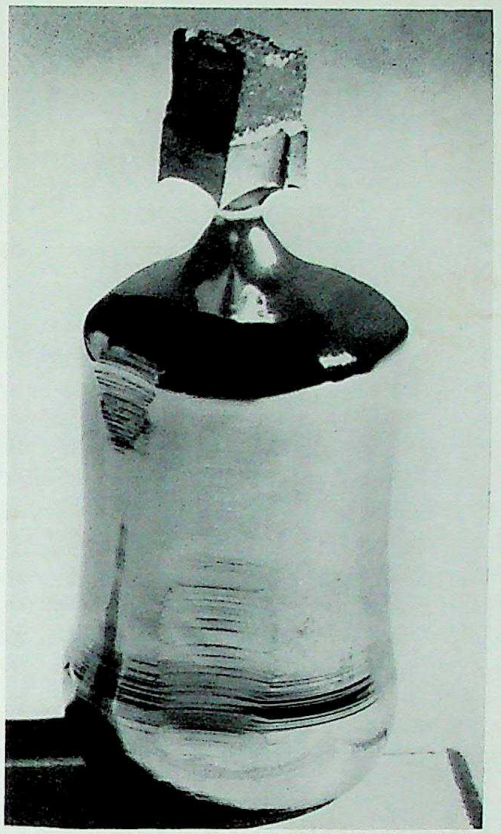

FIGURE 3 – *A large single crystal of germanium.* (× 2)

Further purification of the metal is carried out by a process called zone refining. In this process the carbon boat containing the ingot is drawn at the rate of some 3 inches per hour through a transparent quartz tube filled with nitrogen. During its passage it traverses a laminar high-frequency electric field which is at right-angles to the direction of travel of the boat. At any instant, therefore, only a thin section of the germanium ingot is heated to the melting-point, and passage of the ingot through the heated zone causes a liquid phase, in the form of a wafer, to pass from one end of it to the other. It has been found that this liquid phase carries to the trailing end of the ingot the bulk of the residual impurities, and repeated passage of the ingot through the field results in a very high final purity. Three high-frequency zones are formed in series in the authors' apparatus. With good initial material three passages of the boat through the furnace generally produce an ingot having the required degree of purity; this is determined by measurements of electrical resistivity of the ingot at different points along its length. The result of a typical test on a bar of refined germanium is shown in figure 4. It will be seen that some three-quarters of the ingot has a resistivity of the order of 50 ohm cm, indicating the attainment of the required degree of purity. The less pure part of the bar, defined by its low resistivity, is rejected, the purer portion being used for the next stage to produce single crystal material. Here the technique employed is similar to that used for the production of large crystals of many other elements and compounds. In essence, a seed crystal is partially immersed in liquid germanium maintained at or near the melting-point. The crystal is grown by gradually withdrawing the seed from the melt, the whole operation being carried out in an inert atmosphere. Figure 2 shows apparatus for this purpose developed in the authors' laboratories. A suitable charge of the purified metal, together with a predetermined addition of germanium-antimony alloy, is loaded into the carbon crucible C supported inside a quartz cylinder Q, within which an atmosphere of nitrogen is maintained. A seed crystal S, having the desired orientation, is clamped in the holder H, which can be rotated continuously and raised or lowered. The temperature of the molten charge is then adjusted to just above the melting-point of



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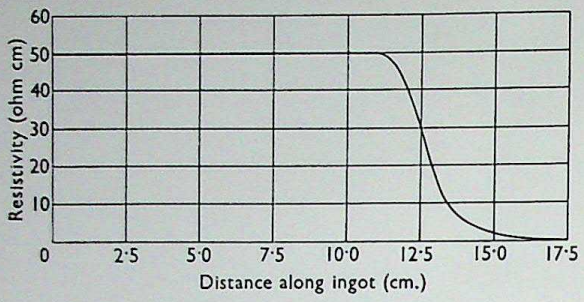


FIGURE 4 – *The distribution of residual impurities in the germanium ingot may be followed by measurements of electrical resistivity.*

germanium by controlling the power in the high-frequency inductance HF, and the free end of the seed is just immersed. By slow withdrawal of the seed, a single crystal of pure germanium can be grown (figure 3).

In practice, in order to obtain accurate and repeatable characteristics, germanium is almost completely purified by zone refining and crystal growing, and controlled amounts of 'impurities' are then added. The impurity content in the final crystal is of the order of one part in 10 million.

### PREPARATION OF CRYSTAL UNITS FOR TRANSISTORS AND OTHER DEVICES

After measurements to make certain that the grown crystal is satisfactory, it is sliced into thin wafers, some 1 mm thick, cut at right angles to the growing axis. These disks or wafers are lapped on each side and are attached to a glass plate by a suitable resin. The plate and the germanium wafer are then diced by a thin, water-cooled cutting wheel to produce, after the resin has been dissolved away to free the germanium from the glass plate, a series of germanium pellets of roughly cubic form.

In one method for assembling transistors one such pellet is soldered on to a small cylindrical brass plug and inserted into an outer case (figure 1). An insulating member carrying the collector and emitter wires, already bent or kinked to give them resilience and accurately set with their chisel-shaped points some 5 or 8 thousandths of a centimetre apart, is then inserted into the other end of the case. The germanium pellet is advanced until its surface makes contact with the two pointed wires, and the assembly is then locked in its final position.

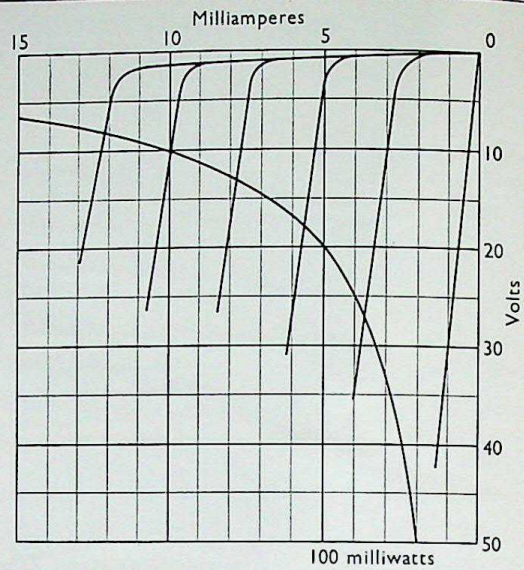


FIGURE 5 – *Characteristics of Siemens point-contact transistor.*

A 'forming' operation follows, in which a number of discharges, from a 1 microfarad capacitor charged to 500 volts, are passed between the phosphor bronze wire and the germanium pellet. No forming occurs with the copper-beryllium wire. After each discharge from the capacitor the characteristics of the transistor are observed, and forming is continued until the desired performance is obtained. Subsequently the body of the transistor is filled with a suitable resin to protect it.

A typical family of curves from a Siemens point-contact transistor for use in switching applications is shown in figure 5. Here collector volts are plotted as ordinates against collector current as abscissae; the traces, from the right, are for emitter currents of 0, 1, 2, 3, 4 and 5 milliamperes respectively. It will be seen that if 20 volts is applied to the collector a change in the emitter current from 0 to 1 milliampere produces a current change in the collector of 0·8–3·4 milliamperes, i.e. the amplification factor is just over 2·5. The line for a loading of 100 milliwatts is shown.

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# Growth substances and plant development

L. J. AUDUS

There is no longer any doubt that the growth of plants is in large measure controlled by the production of minute quantities of physiologically very active substances, but the chemical nature of many of these, and their mode of action, are still obscure. Nevertheless, as this article shows, we now have a fairly consistent picture of some of the substances involved at all stages of growth, and our knowledge is sufficient to turn some synthetic growth substances to very useful account in the production of crops of commercial importance.

The idea that the growth and development of plant organs are controlled by the production and distribution of minute amounts of substances having specific actions is not new. About two hundred years ago Duhamel du Monceau [1] supposed the effect of one organ's growth upon that of another to be due to sap streams moving in opposite directions. Since then the notion that chemical activators control growth has slowly gained ground, although the rival claims of purely nutrient factors generally found greater favour for a time in the eyes of experimental botanists. Finally, in the early 1930s the discovery of the far-reaching and varied effects of β-indolylacetic acid heralded the present era, and both thought and experiment on plant growth in all its aspects have since been completely dominated by this substance and its homologues.

There are, however, many kinds of plant growth substance, differentiated partly by their chemical nature and partly by the way they affect plant growth. Since the same substances can evoke widely different growth responses, and the same growth response can be caused by substances which differ widely in chemical constitution, nomenclature and classification are somewhat confused. The following grouping is convenient:

1. Growth substances that are co-factors of known enzyme systems. Into this category fall the vitamins, which have well established hormone characteristics in plants.
2. Growth substances of known chemical structure but unknown biochemical significance. Here we find the auxins, so christened by F. Kögl and A. J. Haagen Smit [2]. Of their many growth activities the one which characterizes them is the promotion of extension growth of stem tissue. β-indolylacetic acid belongs here.
3. Growth substances whose existence is strongly indicated on indirect evidence, but which have so far eluded isolation and chemical identification. The flowering hormones 'florigen' and 'vernalin', and the specific organ-determining factors or 'calines', belong here.
4. Growth inhibitors produced naturally.

The pattern of growth substances may conveniently be studied by following the cycle of development of the flowering plant from its inception at the fusion of male and female nuclei in the flower, to maturity, when it is itself forming seed.

### THE SEED

Seed formation begins when male nuclei from pollen fuse with female nuclei of the seed primordia (ovules) in the female organ (ovary) of the flower. The young plant embryo develops from the fusion of one male and one female nucleus. At the same time the endosperm, a mass of undifferentiated tissue, resulting from the fusion of one male and two female nuclei, grows round it, filling the rest of the young growing seed. The embryo, which differentiates early into root, shoot, and leaves, does not possess a full complement of enzyme systems. It cannot, for example, synthesize from inorganic nutrients and sugars all its vitamins, and these have to be supplied as such from the tissues of the parent plant. These synthetic abilities are only slowly acquired as the embryo grows. This has been convincingly demonstrated by cutting embryos from the young seed at various stages of development and studying their growth factor requirements in sterile culture media [3]. Thiamin, nicotinic acid, pyridoxine, pantothenic acid, inositol, riboflavine, *p*-aminobenzoic acid, and biotin are the most important



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vitamins that have to be provided. The power to synthesize these vitamins is developed later, although some organs, notably roots, may never acquire it, and always need a constant supply from the aerial parts of the plant.

But these known co-factors are not the only growth substances provided from the surrounding tissues. Excised embryos may still fail to grow on culture media containing all the vitamins known to be essential, although they may succeed if supplied with extracts of endosperm tissue. An ideal source of the unknown factors has been found to be coconut milk, which is virtually liquid endosperm. There are indications that at least two substances may be present, one controlling cell proliferation and another acting as a co-ordinating factor in organ development. Some of these factors have been isolated, but their chemical constitutions are not known in detail.

Many problems of seedling growth still remain to be explored. There is the mystery of why seed leaves (cotyledons) grow to such a huge size compared with the embryonic root and shoot: a growth co-ordinating substance is most probably involved. Why the embryo, when it has reached a certain limiting size, should stop growing and enter into a state of dormancy is still not understood. Only in a very few plants, e.g. the mangrove tree of tropical estuaries, does the embryo continue to grow, and the seed germinate, on the plant without a resting period. This stoppage of embryo growth is presumably imposed by the accumulation of an inhibitor. There is no doubt that the seed coats and the flesh of many fruits contain chemicals which prevent the subsequent germination of the mature seed [4]. The presence of such inhibitors in the fruit flesh probably delays seed germination until the fruit has been dispersed from the plant and the seeds liberated from it. The seed-coat inhibitors may simply be leached out by rain or they may need special external conditions for their destruction. For example, some seeds are stimulated to germinate by light (e.g. lettuce), and this can be explained by a photo-inactivation of the inhibitors of the seed coat. Many natural germination inhibitors are unsaturated lactones.

But this non-growing period of the embryo is not necessarily one of inactivity, since many fundamental changes may be taking place. Many seeds, for example, need a period of dormancy, under particular environmental conditions varying with the species (e.g. low temperatures in apple), before they will germinate. This may be associated with the destruction of a germination inhibitor or with 'maturation' changes in the cells of the embryo. These changes may determine in large part the subsequent developmental behaviour of the growing plant. Thus if sown in the spring the seeds of winter varieties of temperate cereals will not flower and set seed in that season. Such seeds need a certain minimum period of exposure to a temperature near freezing point, to produce a condition in the embryo favourable to rapid flowering when the plant eventually grows. This process of 'vernalization,' as it is called, can be reversed by subsequent exposure to a high temperature [5], provided it is applied within a certain limited period. The most probable explanation of this phenomenon is that the temperature treatments are affecting the level of a flower-promoting hormone, or its precursor, in the embryo, low temperatures favouring its accumulation and high temperatures its destruction. This putative flowering promoter has not yet been isolated, but has been named 'vernalin' [6].

### THE SEEDLING

When the seed is mature and external conditions of light, temperature, and water supply are optimal, it will germinate. This involves the resumption of biochemical activity, in which reserve carbohydrates and proteins are hydrolysed and the mobile products translocated to the embryo for growth synthesis. Root and shoot commence to elongate and push their respective ways out through the seed coat into the substrate. This elongation is under the control of that group of plant growth substances known as the auxins, of which β-indolylacetic acid is the most important, perhaps the only, natural representative. It is produced by the apical growing points, where cell division is actively going on. It is generally held to be produced, by oxidative deamination and decarboxylation, from the amino acid tryptophan, which is mobilized from reserve proteins in the seed. This has not been firmly established, however, although the very close association of β-indolylacetic acid production with organs showing active protein synthesis suggests that it is a by-product of that process, perhaps being synthesized, at the same time as tryptophan, from a common precursor. Many other indole compounds which induce auxin responses when applied externally to test organs of plants have recently been identified in plant extracts. They include β-indolylacetonitrile, β-indolylacetaldehyde, and β-indolylpyruvic acid. The last two may be intermediates in β-indolylacetic acid metabolism. β-indolylacetonitrile and



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FIGURE 1 – *Flower formation in Cabezona pineapple 7 weeks after treating a plant 24 months old with 10 p.p.m. α-naphthylacetic acid. (By courtesy of Dr J. van Overbeek)*

FIGURE 2 – *Selective weedkiller used for the control of charlock in oats. 2,4-D was applied to the top right-hand plot in May: the photograph was taken in July. The lower plot was untreated.*

β-indolylacetaldehyde have probably no auxin activity themselves, but are rapidly converted to β-indolylacetic acid by enzymes in extending cells. The nitrile may have an important role to play as an inactive reserve of auxin potential. Auxin metabolism has been reviewed by S. A. Gordon [7].

Although the control of shoot extension by auxins is well established, the situation in roots is more obscure. Root extension is prevented by concentrations of applied auxin which promote shoot growth. On the other hand, very low concentrations (1 part in $10^{11}$), which stimulate root growth, have no effect on shoots. The position is further complicated by the fact that homologues of β-indolylacetic acid, which antagonize its actions in shoots and roots, may themselves promote root growth in very low concentrations. Whether there is in roots 'No growth without auxin', as postulated by F. W. Went [8] and held to be true for shoots by the majority of plant physiologists, is still a matter for discussion.

There are many synthetic compounds, similar in chemical structure to β-indolylacetic acid, which are extremely active as auxins. They differ

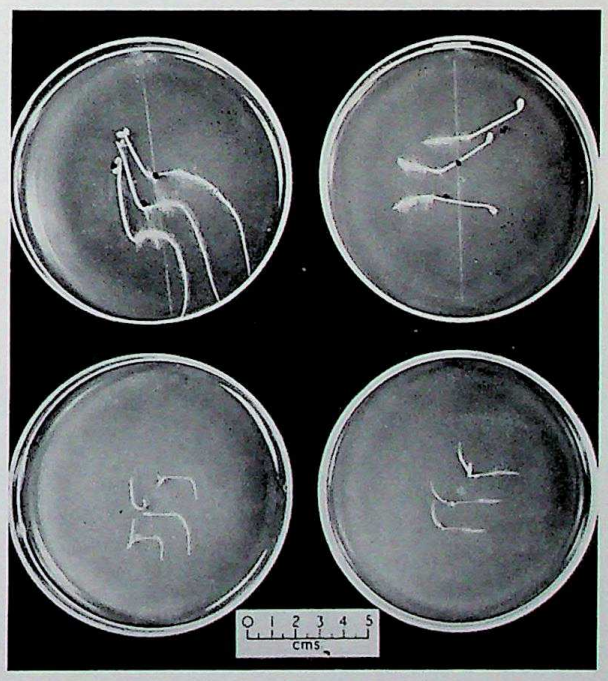


FIGURE 3 – *Antigeotropic effects with rape seedlings (top) and ryegrass (bottom), showing controls (left) and the influence of an active compound (right).* (J. Sci. Food Agric., 5, 32, 1954.)



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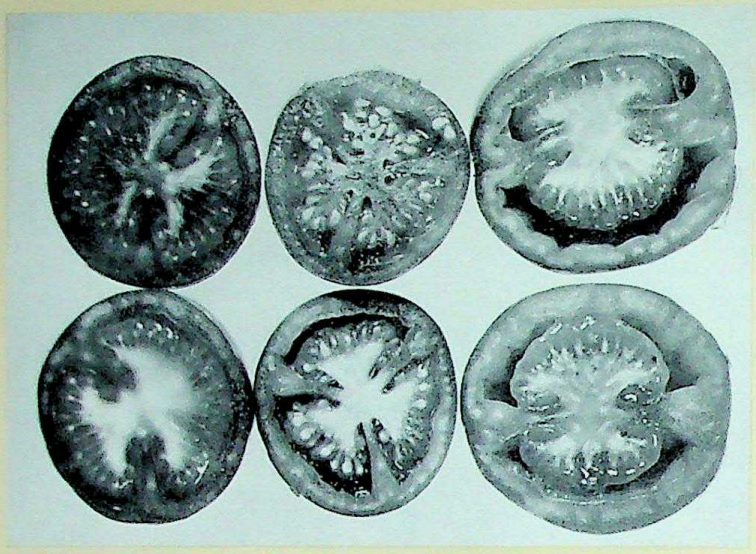

FIGURE 4 – *Sections of tomatoes, showing fruit structure. Centre: Normal seeded tomatoes. Left: Tomatoes set with α-naphthylacetic acid. Fruit of high quality with fully developed pulp, but no seeds. Right: Tomatoes set with 2,4-dichlorophenoxyacetic acid. Fruit of poor quality, with poorly developed pulp and puffy flesh. (By courtesy of the Director, Long Ashton Research Station.)*

FIGURE 5 – *Promotion of flowering in bean by treatment with 2,3,5-tri-iodobenzoic acid (T.I.B.A.). Left: Control (apical bud removed by hand, since it is destroyed by T.I.B.A.). Right: Watered daily with T.I.B.A. (40 ml of a 50 p.p.m. solution). (By courtesy of Dr C. J. Gorter, Laboratory of Horticulture, State Agricultural University, Wageningen, Holland.)*

FIGURE 6 – Iso*propylphenyl carbamate used for the prevention of sprouting in potatoes, stored for 226 days. Left: Control, untreated. Right: Treated at the start of the storage period with I.P.P.C.*



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from natural auxins in that they are highly toxic to plants if applied even in slight excess. Furthermore, the low threshold concentration at which this toxicity sets in varies widely from species to species of plant, thus allowing the use of these compounds as extremely efficient selective weedkillers. Two such compounds that are now used extensively all over the world are 2,4-dichlorophenoxyacetic acid (2, 4-D) and 2-methyl,4-chlorophenoxyacetic acid (figure 2).

The young seedling, in establishing itself, responds with great sensitivity to the stimuli of light and gravity. The developing root system grows in such directions as to explore the maximum soil volume, and the shoot disposes itself to receive optimal illumination for carbon assimilation. There is no doubt that in these responses auxins play a central role. Thus unequal illumination of sensitive organs leads to spatial differences in auxin concentration. The resulting differential growth brings about curvatures in the organ concerned and re-orientation towards the source of the light. The underlying cause of this redistribution of auxin is still only partially understood. There is strong evidence that β-indolylacetic acid undergoes a photo-oxidation in which riboflavin acts as the sensitizer, but the complexity of response to different light intensities shows that this cannot be the only factor concerned. The geotropic response has also been attributed to a redistribution of auxin. There is direct evidence that auxin does accumulate on the lower side of horizontally disposed shoots, thus stimulating the growth of the lower half and causing a re-orientation of the shoot into the vertical position. In horizontally placed roots, the same accumulation on the lower side is supposed to inhibit growth there and hence cause a downward trend. The experimental evidence for this is much less convincing, especially in view of the uncertain role of auxins in root growth. In some organs, e.g. underground stems that grow horizontally and at a constant level below the soil surface, the distribution of at least two different hormones may be involved in maintaining this adjustment [9, 10].

Recently compounds have been discovered which disturb the mechanism of root response to gravity, presumably by interfering with the natural hormone system (figure 3). The use of such compounds may prevent the establishment of the roots of weed seedlings and thus provide a new approach to weed control [11].

Growth factors other than auxins seem to play a part in the growth of leaves. Darkness causes seedlings to grow tall and spindly, a response usually attributed to their higher auxin content, while the same environmental conditions prevent the expansion of leaves. The growth of leaf blades has been shown to be promoted by the organic base adenine, an essential component of the nuclear proteins and of many important coenzymes associated with the supply of metabolic energy. Other unknown factors are undoubtedly involved. The extension of leaf veins, however, is apparently promoted by auxins. It is not surprising, therefore, that the application of synthetic auxins, which are not metabolized to any extent by plant tissues, can alter the balance of growth factor requirements and bring about dramatic changes in leaf form. Indeed, such active and stable auxins as 2,4-dichlorophenoxyacetic acid can markedly inhibit blade expansion and cause a wide variety of deformities.

### THE DEVELOPING PLANT

As the plant increases in size new organs come into being, and the form characteristic of the adult is assumed. In the above-ground parts of many plants this will be largely a result of the number and position of the lateral branches arising from the buds situated in the leaf axils. The early growth, and hence subsequent development, of these lateral buds is suppressed by the terminal bud of the main shoot or branch. The kind of development which ensues will depend largely on the behaviour and fate of this terminal bud. This phenomenon of apical dominance plays a major role in determining the shape of most plants. Auxin produced by the apical bud has long been claimed by many as the mediator of this correlation phenomenon, being translocated from this centre of production to the laterals, which are then inhibited. Other workers have postulated a special inhibitor whose production is associated with auxin levels. Non-auxin growth inhibitors showing some of the physiological properties of this theoretical substance have recently been extracted from plants, but they have not yet been identified. Again the story is not as simple as this would suggest. For example, when a solution of the synthetic growth inhibitor, maleic hydrazide, is sprayed on plants, it may remove apical dominance and allow laterals to grow out. This suggests that there is a real difference in the sensitivity of different buds to growth substances, and this may contribute considerably to correlative behaviour. But we should not be too prone to attribute every growth phenomenon solely to hormone action.



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Work under F. G. Gregory [12] has shown conclusively that, in flax at least, competition for a nutrient (nitrogen) may play an over-riding part in determining apical dominance. Both synthetic auxins (e.g. the methyl ester of α-naphthylacetic acid) and growth inhibitors, such as maleic hydrazide and *iso*propylphenyl carbamate, are being used for the suppression of bud growth (sprouting) in stored vegetables (e.g. potato, carrot, onion), thus preventing the wastage that could otherwise occur in the later stages of storage (figure 6).

The formation of lateral roots is undoubtedly affected by auxins, since it can be greatly promoted by external applications of these substances. A very important practical application of this phenomenon is in the promotion of root formation in plant propagation by cuttings. Much indirect evidence exists for the participation of other factors in natural root genesis. One is a hypothetical 'rhizocaline' provided from shoots. In view of the complex vitamin requirements shown by excised roots growing on artificial media containing sugars it is not impossible that this 'rhizocaline' may be a vitamin. Since lateral roots are always produced in a special internal tissue layer, a third rooting factor, strictly confined to these cells, has been postulated.

In perennial woody plants growth in girth of stems takes place by the activity of a sheath of special cells (cambium) situated between wood and bark. This growth activity is highest in the spring and declines as summer advances, and accounts for the formation of annual rings in trees growing in temperate climates. This rhythm is exactly correlated with auxin production by the young buds in the spring, a wave of auxin from the buds flowing down the cambial sheath of cells and initiating and promoting its growth activity. Again other factors are involved, since these cells will not react to applied auxins in the winter when in a dormant condition. Dormancy has first to be broken (e.g. by treatment with ethylene) before the cells can respond. The same cells are responsible for the production of tissue (callus) to cover wounds in trees. From time to time special wound hormones (e.g. traumatic acid, $COOH.CH{:}CH.(CH_2)_8.COOH$) produced by the damaged cells have been claimed as the determining factors of wound response.

Whereas in most perennial woody plants branches persist and grow for the whole life of the plant, leaves reach maturity at an early stage and show no further growth. After a season or so of active synthesis, they are shed and are replaced. Leaf fall is brought about by the loosening of the cells in a special cell layer (abscission layer) at the base of the leaf stalk. The strength of the stalk in that region is thereby lost and the leaf is then readily removed by any mechanical disturbance, such as wind. Abscission takes place when the leaf has become senescent and its synthetic powers have failed; its direct cause is the declining supply of auxin from the blade. Auxin presumably acts, either directly or indirectly, by inhibiting the enzymes responsible for the biochemical changes causing the loosening of cells of the abscission layer from one another.

## REPRODUCTION

In higher plants the switch to the reproductive state, when some of the growing points change the course of their development to produce flower primordia instead of leaf primordia, is determined very largely by the onset of particular day-lengths and by previous temperature conditions. The associated phenomena are too extensive and complicated for any general statement in an article such as this, but there is very compelling evidence that a flowering hormone is involved [13]. Day-length discrimination is carried out by the leaves, which, under optimal lengths of day and night, originate some kind of influence which passes thence to the growing-points and induces the change-over from the vegetative to the flowering state. This influence will pass a graft union, suggesting that it is a chemical substance. On the other hand, it will not diffuse across a water gap between two such graft partners, and this suggests that simple diffusible substances are not involved. So far, the insuperable obstacle to the acceptance of the existence of flowering hormones has been that, despite many and repeated attempts, no extract from a flowering plant has yet caused flowering when applied to vegetative plants.

It is natural that auxins, active in so many growth processes in plants, should have been thought of in connection with flowering. Undoubtedly they do affect flowering behaviour, but their true role in flower induction is still very obscure. Many now believe that auxin, although not itself a flowering hormone, must be present at an optimal level if flowering is to take place. The situation is by no means clear, however, since some plants (e.g. pineapple) can be induced to flower by auxin (α-naphthylacetic acid) application (figure 1), while in others flowering is greatly promoted by the application of substances which are regarded as antagonists of auxin action (e.g.



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2,3,5-tri-iodobenzoic acid in the bean (figure 5)). Direct indications from assays of natural auxins during flower induction and development show marked changes in free auxin concentrations, but there is no consistent picture. The effect of synthetic auxins on flowering has been fully exploited in the pineapple industry, where the date of fruiting can be precisely determined by carefully timed sprays of very dilute α-naphthylacetic acid solutions. This completely obviates the difficulties of harvesting and marketing previously resulting from the normal random spread of fruiting.

When a flower is fully developed and conditions are suitable, it is pollinated. Pollen grains germinate on the receptive part of the female organ (stigma) and pollen tubes penetrate to the ovules, where the nuclear fusion mentioned earlier takes place. The pollen brings with it not only male nuclei for fertilization but also a supply of β-indolylacetic acid which triggers off the growth processes of the young fruit. If this auxin stimulus is not received, then an abscission layer forms across the base of the flower stalk and the unfertilized flower is shed. Once the growth of the young fruit and its contained seed has started, there is a continued production of auxin which prevents this layer forming and also maintains the growth of the fruit tissue. In some fruit, particularly seedless varieties, sufficient auxin is produced in the fruit tissue itself, but in most plants the young embryo and the endosperm are the sources of this hormone for fruit growth. Recent work under L. C. Luckwill has demonstrated waves of auxin production during fruit development in both apple [14] and blackcurrant [15]. At least three hormones may be involved. The well known shedding of small immature fruit (June drop) and the ultimate fall at maturity are both closely correlated with low levels of auxin at these two stages in the life of the fruit. As the fruit grows there gradually accumulates in the flesh the germination inhibitor described at the beginning of this article.

Synthetic auxins have two very important applications in fruit growing. Under conditions unfavourable for pollination dilute solutions can be sprayed on flowers to induce the setting of the fruit and subsequent production of a full crop, which will of course be largely seedless. This has its greatest application in commercial tomato growing (figure 4), and is being extended to other fruits such as figs and grapes. Synthetic auxin sprays can also be used to retard the abscission and fall of maturing fruit, such as apple, thereby reducing damage and loss and also allowing greater flexibility in the planning of harvesting operations. An incidental advantage is that the post-harvest ripening and quality of the fruit may be improved. At all stages in the growth and development of plant organs specific growth substances seem to be in control. So far research has been dominated by studies on the auxins, in particular β-indolylacetic acid, but with the application of paper chromatography to the study of plant growth substance, and the development and refinement of assay methods, we look forward to the isolation in the not too distant future of other postulated substances that have so far eluded identification.

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# The history of the marine chronometer

SIR HAROLD SPENCER JONES

The accurate determination of position at sea now presents so few problems, unless weather conditions are so adverse as altogether to preclude astronomical observation, that it is perhaps difficult to appreciate the very grave difficulties it presented to navigators less than two hundred years ago. As the precise determination of longitude depends directly upon the availability of an accurate timepiece, the marine chronometer, the development of which is traced in this article, is a navigational instrument of absolutely fundamental importance.

The problem of finding the longitude of a ship at sea for long defied solution. The longitude difference between two places is equal to the difference between the local times of the two places at the same instant. The determination of local time by a ship at sea presents no difficulty; the determination of its longitude relative to some standard meridian therefore depends upon knowing the time on that meridian. If the ship can be provided with an accurate timepiece, set to the time on the standard meridian, the problem is solved.

The use of a timepiece for determining longitude at sea was first proposed in 1530 by Gemma Frisius, in his *De Principiis Astronomiae et Cosmographiae*. But the timekeeping of the clumsy watches of his day was far too erratic to be of any value. The first attempt to design and construct a timepiece that would keep time at sea was made by Huygens in 1660. His marine clock was controlled by a half-seconds pendulum; when tried at sea it proved to be hopelessly erratic, as the slightest motion of the ship upset the pendulum. He then replaced the pendulum by a balance and balance spring, but the lack of a method of compensating for changes of temperature, and various other defects, resulted in poor timekeeping.

The next attempt of importance was made by Henry Sully (1680–1728), a former apprentice of George Graham, the leading English horologist. Newton and Wren turned Sully's attention to the problem of constructing a clock for use at sea. He made several marine timepieces, one of which is in the Museum of the Clockmakers Company in the Guildhall, London. An oscillating horizontal bar, connected with the balance by a silk cord working between cycloidal cheeks, replaced Huygens's pendulum. The escapement, of his own design, had some merits, and friction rollers were used for the first time to minimize friction at the pivots. Trials made in sheltered waters in 1726 were promising, but those on the open sea were a failure. The oscillating bar was a horizontal pendulum and was influenced by the accelerations produced by the pitching and rolling of the ship. Sully designed also a marine watch, which he mounted in gimbals; it had some promising features and might have been developed into a satisfactory timekeeper, but his comparatively early death put an end to his experiments.

A solution to the problem of determining the longitude at sea had become so urgently needed that in 1714 the British Government offered an award of £10,000 for any method capable of determining a ship's longitude within one degree, of £15,000 if within 40 minutes, and of £20,000 if within 30 minutes. A permanent body of Commissioners, known as the Board of Longitude, was appointed to adjudicate on applications for the award; they were empowered to pay one half of the award when the majority of the Board was satisfied that the method was practicable and useful, the other half when a vessel using the method had sailed to a port in the West Indies without erring in her longitude by more than the specified amount.

Many quite impracticable schemes were submitted to the Board. It was not until 1764 that all the conditions for the award were successfully met, by a timepiece constructed by a Yorkshire carpenter and mechanic, John Harrison (1693–1776); owing to conditions imposed by the Board, however, payment of the award in full was not made until 1772. In 1728 Harrison took to London the drawings of a marine clock he had designed, in the hope of obtaining assistance from the Board of Longitude for its construction. On Halley's advice he showed his drawings to Graham, who discerned their promise and lent him £200 without security or interest to enable him to carry on with the construction.

In 1735 Harrison completed his first marine



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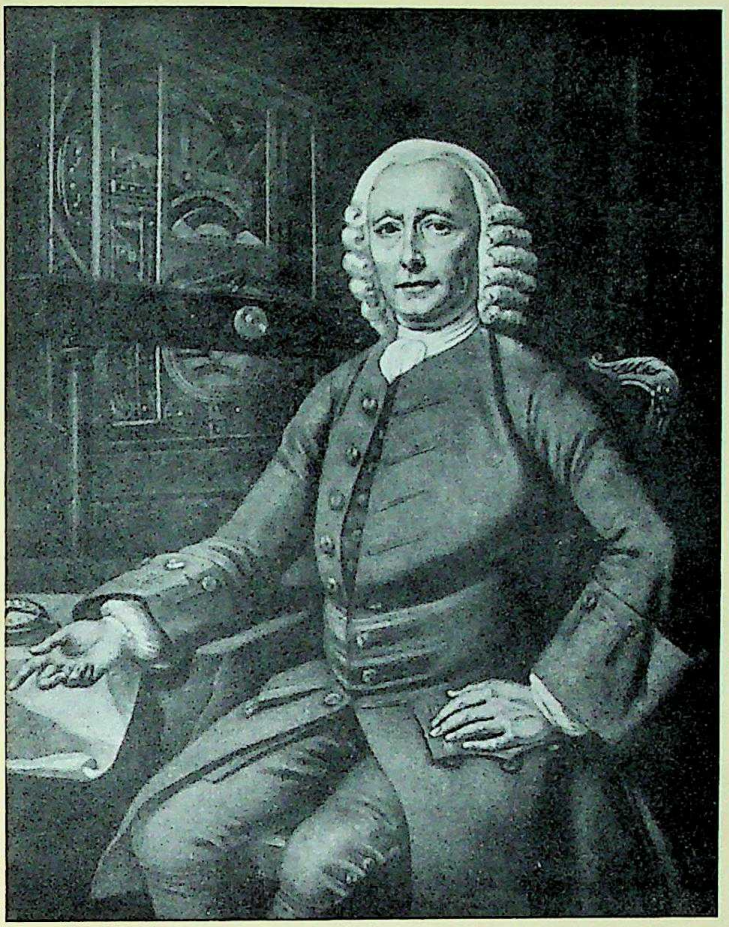

FIGURE 1 – *John Harrison (from a mezzotint by Tassaert, published in 1768, after a painting by King). His machine No. 3 is behind, and No. 4 is on the table.*

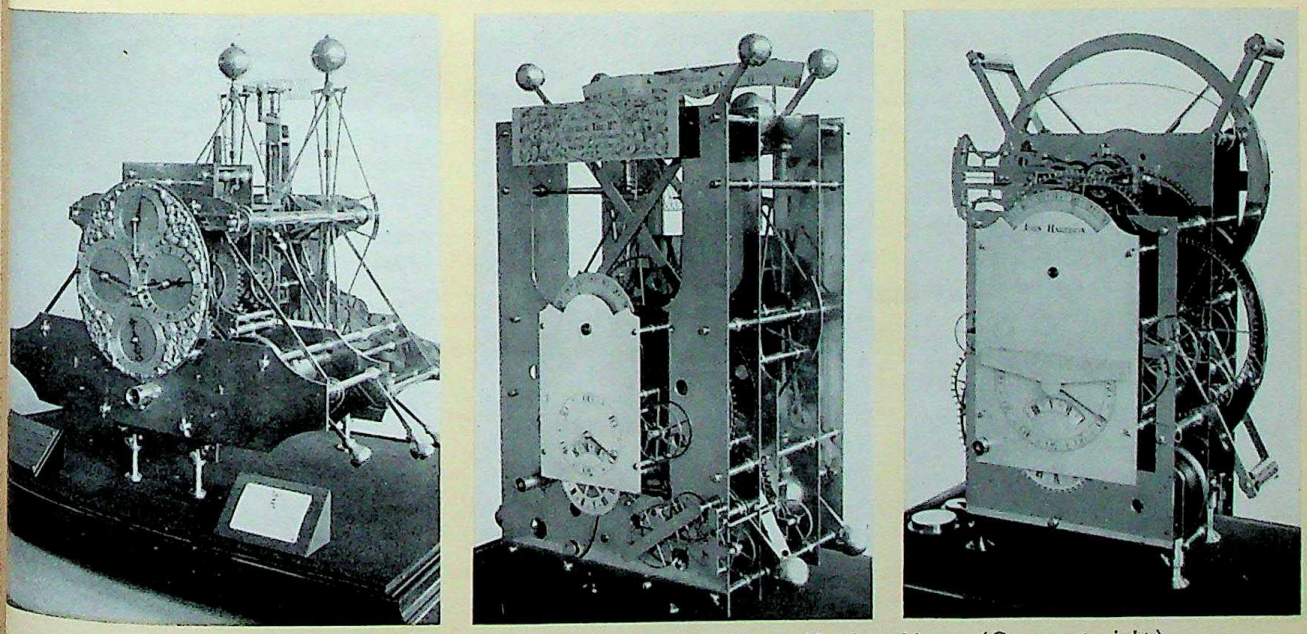

FIGURE 2 – *From left to right: Harrison No. 1, Harrison No. 2, Harrison No. 3. (Crown copyright.)*



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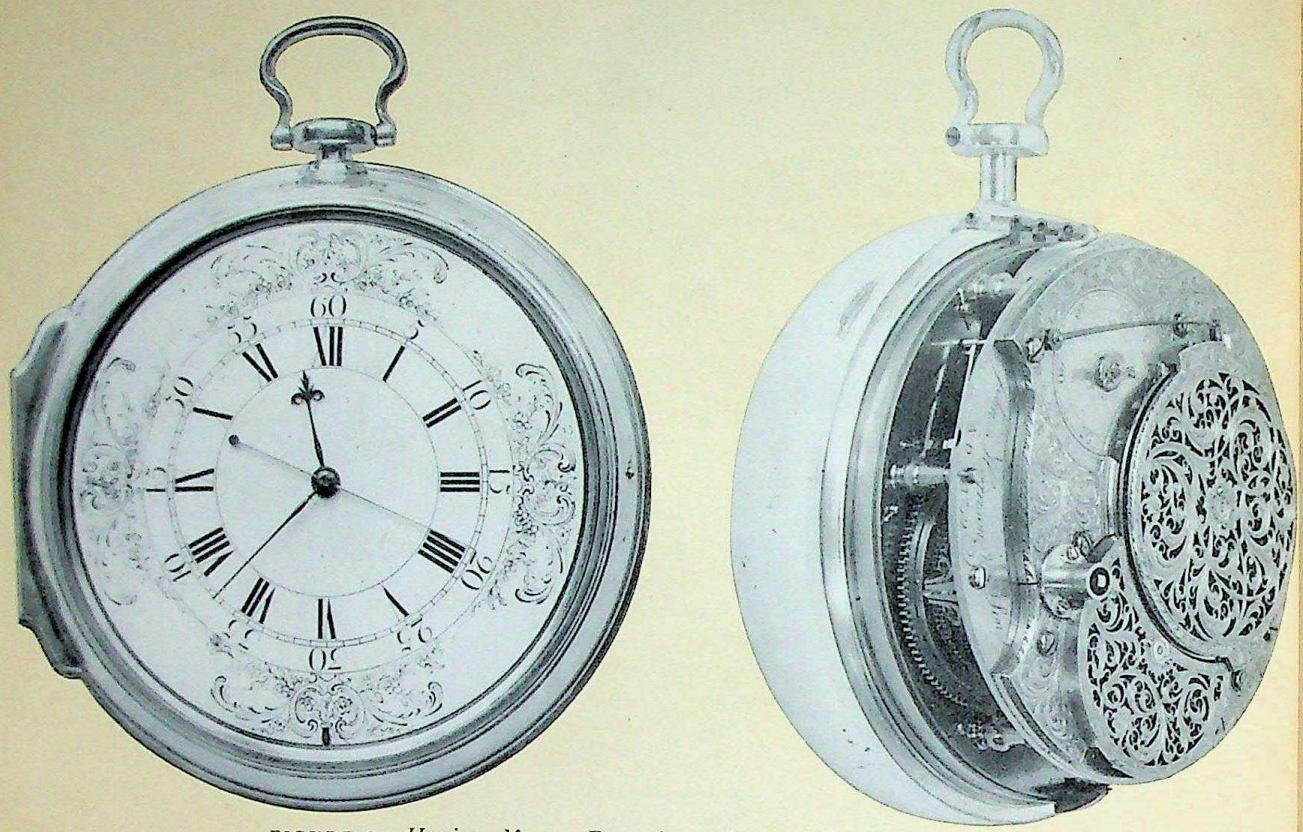

FIGURE 3 – *Harrison No. 4. Front view and movement. (Crown copyright.)*
*(Figures 2 and 3 are reproduced from the originals in the National Maritime Museum, by permission of the Admiralty.)*

FIGURE 4 – *The back plates of Harrison No. 4 and of Larcum Kendall No. 1.*



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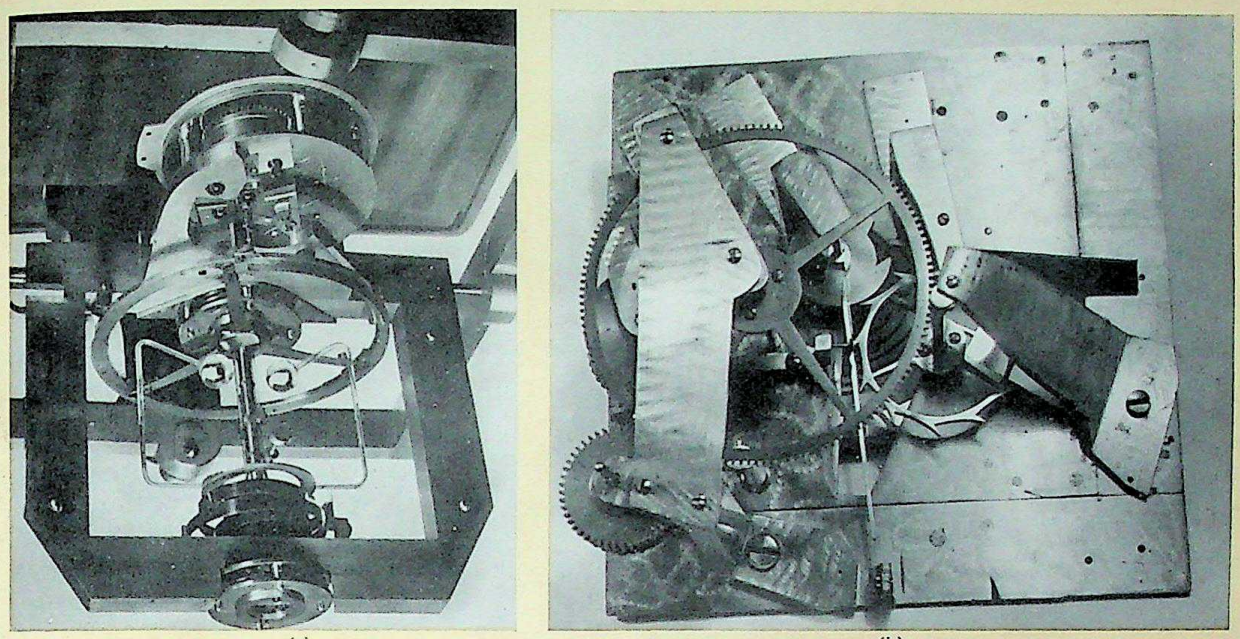

(a) (b)

FIGURE 5 – (a) *Le Roy's* Montre Marine, *showing thermometers attached to balance staff.* (b) *Earnshaw's model of his spring-detent escapement, made for the Board of Longitude in* 1804.

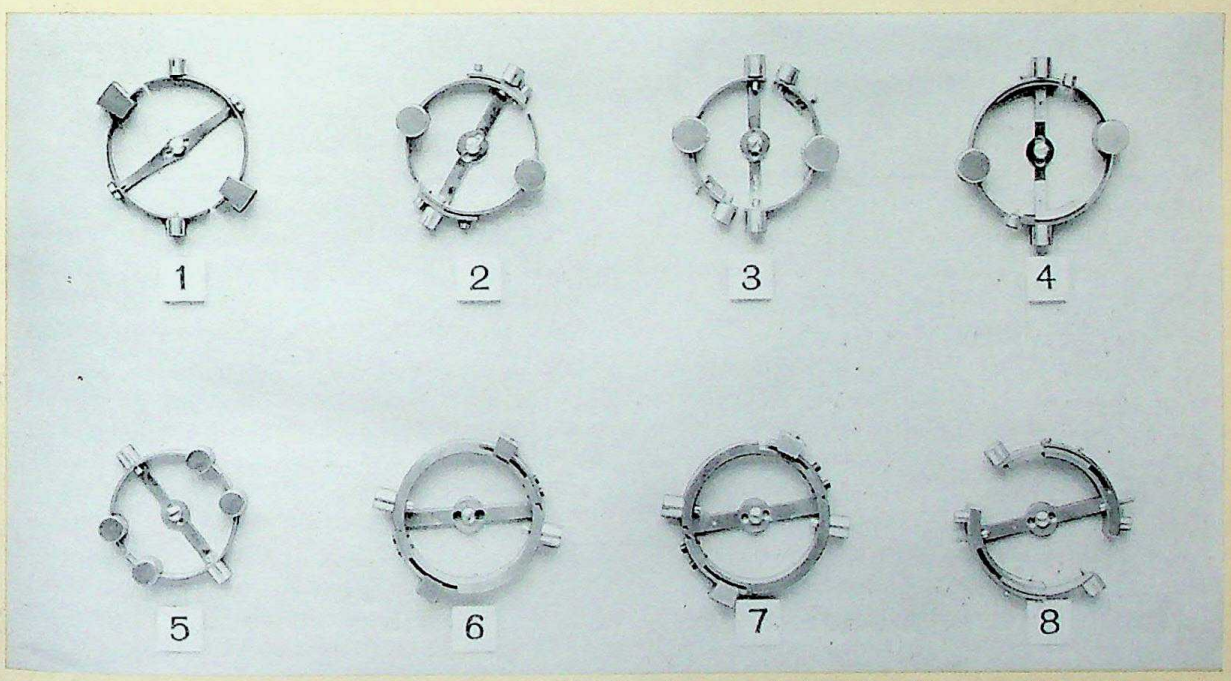


FIGURE 6 – *Types of compensation balance.* 1. *Modified Earnshaw type, having bimetallic arms. The positions of the small screws can be varied to vary the amount of compensation.* 2. *Poole's auxiliary compensation. Inward movement of the bimetallic arms with rise of temperature is unrestricted; outward movement with fall of temperature is somewhat restricted by the small screws on the short arms.* 3. *Kullberg's auxiliary compensation. Two small extra bimetallic arms are fitted, which can move inwards with rise of temperature but cannot move outwards with fall.* 4. *Mercer's auxiliary compensation. Similar in principle to Kullberg's.* 5. *Guillaume balance, which has four equal bimetallic arms, made of brass and a special nickel-steel, whose expansion coefficient is greater at low than high temperatures.* 6. *Uncut Invar balance with bimetallic affixes. The short bimetallic blades provide compensation for small residual temperature effects.* 7. *Uncut brass balance with bimetallic affixes. Similar to Guillaume's, but with heavier weights because greater compensation is required.* 8. *Balance with bimetallic affixes, for use with Elinvar balance spring. Compensation is varied by sliding the bimetallic affixes inwards or outwards.* (*From the set in the Science Museum, South Kensington. Reproduced by permission of Messrs. Thomas Mercer.*)



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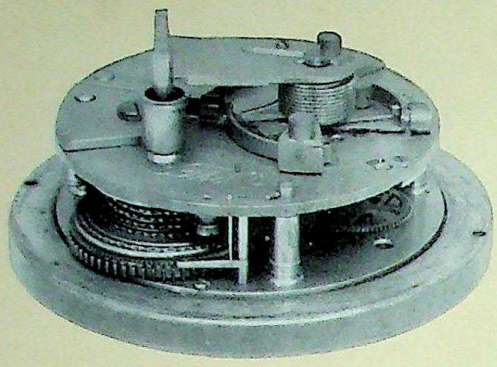

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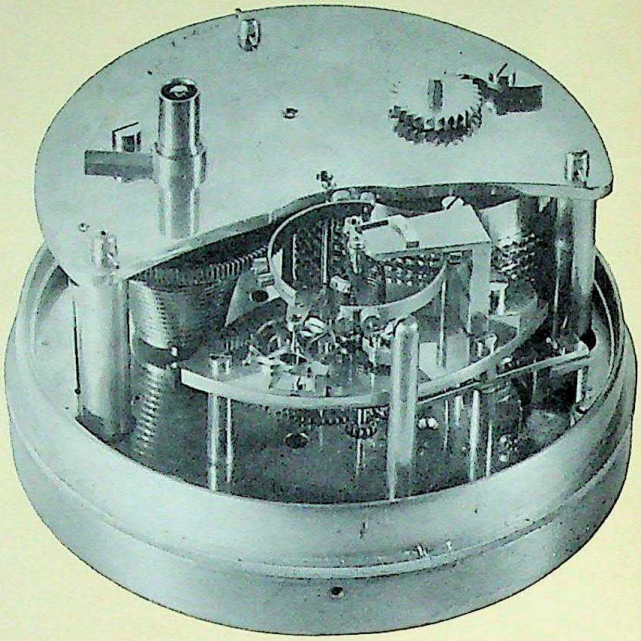

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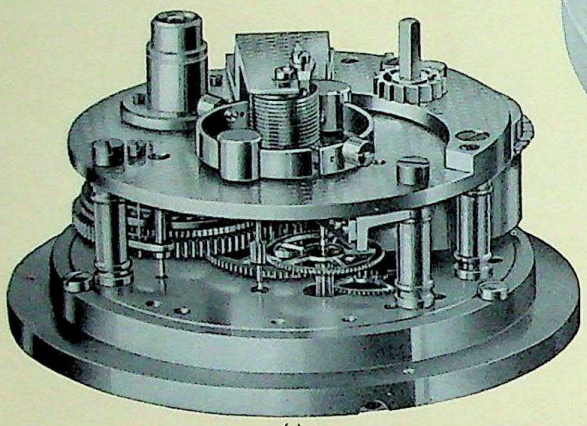

(c)

FIGURE 7 – *Examples of chronometer movements.* (a) *T. Earnshaw* (*c.* 1820). (*Crown copyright. From the chronometer in the Science Museum, South Kensington.*) (b) *A. L. Breguet* (*c.* 1800). (*By courtesy of the trustees of The National Maritime Museum.*) (c) *Thomas Mercer* (*c.* 1950).

FIGURE 8 – *Early and modern chronometers. Left to right: Thomas Mudge No.* 4 (*c.* 1790), *V. Kullberg* (*c.* 1916), *R. Pennington* (*c.* 1796), *and, in foreground, Thomas Mercer* (*c.* 1930) (*survey chronometer, with contacts*).

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timepiece and submitted it for trial. In many respects it was a remarkable and ingenious machine. It was controlled by two large balances, connected together by wires running over brass arcs so that their motions were always opposed, thereby counteracting the effects of a ship's motion. Four helical balance springs were used, and a gridiron arrangement was employed which, by slightly moving their inner ends, changed their tensions sufficiently to compensate for changes of temperature. The escapement was original in design and was practically frictionless. The machine, which weighed 72 pounds, was mounted in gimbals and tested on a voyage to Lisbon and back with encouraging results.

Harrison did not enter this timepiece for the full trial, but proceeded to construct a second, which was completed in 1739. In principle it was generally similar to the first, but with various improvements in detail. But it was not tested at sea, for in 1741 Harrison informed the Board that he was engaged upon a third machine which would surpass the first two. This machine was not completed, however, until 1757. The two balances, circular in form, were connected together by wires and controlled by a single flat spiral spring. Temperature compensation was provided by a device, termed a compensation curb, whereby the effective length of the spring was determined by two curb pins, whose position was controlled by a bimetallic strip.

On its completion, Harrison informed the Board that he proposed to apply for a trial at sea when he had completed a smaller timepiece, intended to be used with it as a deck-watch. This timepiece, completed in 1759, was a large pair-case watch, five inches in diameter. The large steel balance was controlled by a spiral steel spring, provided with a compensation curb, and its escapement was a much modified and improved type of verge. A most ingenious remontoire was provided, in which the spring was rewound every $7\frac{1}{2}$ seconds, so that the driving force to the escapement remained practically constant.

Its timekeeping proved to be so good that Harrison decided to rest his claim for the award on its performance, and not to submit his large third timepiece for trial. In 1761 it was taken to Jamaica and back in H.M.S. *Deptford*, being tended by his son William. Its performance exceeded all expectations: the longitude of Jamaica was determined with an error of only $1\frac{1}{4}'$, or approximately $1\frac{1}{2}$ miles. But though the requirements for the maximum award had been met, the Board felt that this accuracy might have been a fluke. A further trial was therefore arranged; the timepiece, again in charge of William Harrison, was placed on board H.M.S. *Tartar*, and the longitude of Jamaica was determined with an error of $9\frac{1}{2}'$. On the return to Portsmouth it was found that in 156 days it had gained only 56 seconds.

But the Board was still not satisfied, on the ground that Harrison had not explained the principles of its construction. The final instalment of the award was paid only after Harrison had taken the timepiece to pieces before a committee nominated by the Board and after a duplicate had been made by another clockmaker. Larcum Kendall (1721–95) was chosen for this purpose, and completed the copy in 1770. This copy was taken by Captain Cook on his second and third great voyages in H.M.S. *Resolution*, and was paid glowing tribute by him. He remarked in his journal: 'Our longitudes can never be erroneous while we have so good a guide as Mr. Kendall's watch.'

Harrison's four timepieces and the Kendall copy of No. 4 are in the possession of the Royal Greenwich Observatory and are on loan to the National Maritime Museum at Greenwich, where they may be seen, all in going order.

The great achievement of Harrison was the proof that a timepiece could be constructed that was capable of keeping accurate time in a rolling and pitching ship. He realized the essential requirements for achieving this, but because of the complications of the design and the difficulties of construction none of Harrison's ingenious inventions has survived in the marine chronometer of today.

Thomas Mudge (1715–94), the inventor of the lever escapement now almost universally used in watches, became interested in marine timepieces after examining Harrison's No. 4. He made modifications to Harrison's design which were in the direction of over-elaboration instead of simplification; they included a constant-force escapement which, though perfect in theory, required an unusual degree of skill in construction. Mudge's workmanship was exquisite in its perfection, but was without influence on the subsequent development of marine timepieces.

The problem of designing a marine timepiece was meanwhile being tackled in France by Pierre Le Roy (1717–85) and Ferdinand Berthoud (1729–1807). Le Roy developed the first timepiece to embody two essential features of the



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modern chronometer: the compensation balance and a 'detached' escapement, in which the balance is free from interference for almost the whole of its swing. He compensated for temperature changes by fitting two small thermometers to the staff of the balance, arranged so that with change of temperature the expansion or contraction of the mercury altered the moment of inertia by the amount needed to compensate for the change in the dimensions of the balance and the change in the strength of the balance spring. Le Roy completed his *montre marine* in 1766; it was tested at sea on a voyage to Newfoundland, when its performance was about equal to that of Harrison's No. 4.

Berthoud completed his first marine timepiece, which was a large, clumsy affair, in 1763. He was a man of extraordinary industry and of great originality. Trying one idea after another, and making successive improvements, he developed a timekeeper which in its essentials was not greatly different from the modern chronometer. He invented many different escapements, including several of the pivoted detent type and a spring detent escapement, of which he published a description in 1787. He made more than seventy marine timepieces in all.

So long as the making of a marine chronometer in its entirety remained the task of an individual highly skilled craftsman, the rate of production was necessarily slow and the cost was high. Two men in England, John Arnold (1736–99) and Thomas Earnshaw (1749–1829), converted the making of chronometers into a commercial proposition by simplifying the design as much as possible and employing workmen to do the subsidiary work and, after tuition, the more complicated and delicate parts also. They themselves undertook the final springing and adjusting, their methods being closely guarded as trade secrets. Each of them produced more than a thousand chronometers, at prices much below those of other makers.

Arnold made and patented several improvements in design. He devised several types of compensation balance and introduced the helical balance spring, now in general use. His first pivoted detent escapement was a somewhat clumsy affair, but he developed from it an efficient spring detent escapement which was used in all his subsequent chronometers.

To Earnshaw we owe the designs of the compensation balance and of the spring detent escapement (figure 9), which are essentially those in use today. Whether priority for the invention

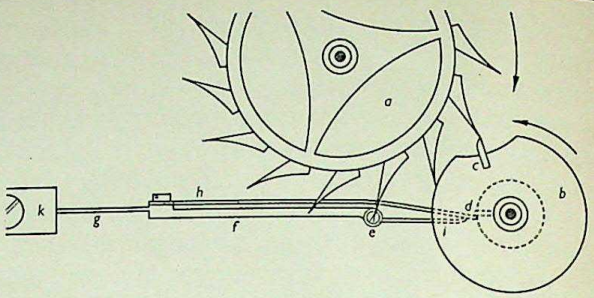


FIGURE 9 – *The spring-detent escapement. Key:* a, *escape wheel;* b, *impulse roller, attached to balance wheel;* c, *impulse pallet;* d, *unlocking pallet;* e, *locking pallet;* f, *detent;* g, *detent spring;* h, *passing spring;* i, *nose of detent;* k, *detent spring pad.*

of the spring detent escapement should be given to Berthoud, Arnold, or Earnshaw has been much discussed. They were probably working independently along similar lines, though perhaps each knowing something of what the others were doing. The spring detent was a natural development from the pivoted detent; it eliminated the irregularities caused by the thickening of the oil in the pivot. Earnshaw's design is the simplest in construction and the most efficient in operation. His original model, made by him for the Board of Longitude, is in the possession of the Royal Greenwich Observatory (figure 5).

The principle of this ingenious escapement may be seen from the figure. The detent, which carries the pallet for locking or 'detaining' the escape wheel, is attached to the detent spring, together with a light flexible spring made of gold, called the passing spring. The impulse roller, with the impulse and discharging pallets, is attached to the balance. In the position shown, the discharging pallet is about to trip the passing spring and to unlock the locking pallet, permitting the escape wheel to move forward. As it does so, the tooth adjacent to the impulse pallet gives an impulse to the pallet to maintain the oscillation of the balance. Meanwhile the detent spring has brought the locking pallet back to its original position, ready to lock the next tooth of the escape wheel. On the return swing of the balance the discharging pallet deflects the passing spring, which is so light that the effect on the balance is negligible. Thus the balance is almost completely detached, i.e. free from interference. An important feature of this escapement is that it requires no oiling.

Earnshaw brought the chronometer essentially to its modern design. Subsequent developments have been merely in matters of detail. It is surprising that in little more than half a century the



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whole development from Harrison's timepiece, which won the £20,000 award, to the commercial development of the chronometer as we know it today, took place.

The principal modifications that have been made to chronometers since the time of Earnshaw may be summarized briefly. Arnold had found that the isochronism of the balance fitted with a helical spring depended on the shape of the terminal curve of the spring, and by trial he developed the shape of the curve that gave the best isochronism. In 1861 the French mathematician, Phillips, investigated the requirements for isochronism and showed that it is necessary for the centre of gravity of the spring to coincide with the axis of the balance. This condition is more easily satisfied with a helical spring than with a flat spiral spring, and the form of terminal used by Arnold complied closely with it.

Improvements have been made to the balance to provide better temperature compensation. With Earnshaw's design it is possible to adjust so that the chronometer has the same rate at two selected temperatures. Within this range of temperature the chronometer will gain slightly, and outside it will lose slightly. This effect is known as 'middle-temperature error'. Much ingenuity has been exercised to get rid of this error by the use of auxiliary compensations, of which there seem to have been as many different designs as makers of chronometers. The researches of Guillaume on the properties of nickel-steel alloys led him to the discovery of Invar, an alloy with a negligible coefficient of expansion, and of Elinvar, an alloy with a zero elasticity-temperature coefficient, which have found a useful application in chronometers. Elinvar balance springs were introduced by Ditisheim in 1920, while Hamilton employs an uncut balance of the invar type in conjunction with an elinvar spring. Careful control over the uniformity of the properties of these alloys is essential for their use in commercial manufacture, and they are best prepared in small quantities as a laboratory operation.

The design of the modern chronometer is such that uniformity of timekeeping to one or two tenths of a second a day over a wide range of temperature is attainable. For this precision great care in manufacture is essential; a high degree of finish, especially in the pivots, is needed; the materials must be carefully selected; the wheels of the movement must be accurately cut; and the oils used must be of suitable viscosities and have low viscosity-temperature coefficients.

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# Book reviews

### STATISTICAL ANALYSIS IN CHEMISTRY

Statistical Analysis in Chemistry and the Chemical Industry, *by C. A. Bennett* and *N. L. Franklin. Pp. xvi + 724. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 58*s. net.*

This is, on the whole, an attractively and lucidly written book, with many well chosen examples, and frequent reference to the underlying mathematical theory. Indeed, the amount of algebra seems at times unnecessarily formidable: there can be little advantage in proving at length, in an applied text, results that can perfectly well be accepted and understood by analogy with more fundamental formulae, detailed proofs of which are justifiably included. The chapter on the analysis of variance suffers particularly from this attempted comprehensiveness. This chapter shares two other faults with most texts on industrial statistics. All expected mean squares in analysis of variance tables are expressed in terms of variance components, even when this is admitted in the text to be inappropriate; and the dangerous practice, which may result in a biased variance, of pooling all non-significant effects with error is recommended and followed throughout. Many recently developed techniques are included, some valuable, others trivial refinements: more guidance on the relative importance of alternative methods would have been welcome. Despite these criticisms, this is an excellent survey of the field, and well worth the attention of any reader prepared to tolerate a certain amount of heavy, rather than advanced, mathematics.

M. R. SAMPFORD

### PARADOXES

A Budget of Paradoxes, *by Augustus de Morgan* (with a new introduction by E. Nagel). *Pp.* 387. *Dover Publications Inc., New York.* 1954. $4.95 *cloth net.*

This very welcome reprint of a famous work by Augustus de Morgan is now issued in one volume. It is enriched with a short introduction by Professor Ernest Nagel of Columbia University, and it contains all matter, without omission, from the first and second editions. It is needless to recommend this delightful book to mathematicians. It most entertainingly discusses mathematical paradoxes in the manner of a commonplace book or bedside book. There is no method or order in the contents, but the errors of circle squarers are well to the fore. Mathematical paradoxers are among the camp-followers of science, but they



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certainly should have their place in any comprehensive history of mathematics. Their errors, their prejudices, their ignorance, combined with their highly developed logical powers, would form a veritable series of case studies for the psychiatrist and the educationist. The reviewer cannot refrain from making two final comments. First, it is a tribute to the easy and unhurried life of professors in the spacious days of Queen Victoria that de Morgan had the time, energy, and opportunity to write so much about such apparently trivial matters. Secondly, it is very pleasant to recollect that many of these papers by de Morgan were originally published in the *Athenaeum*, a grave and serious periodical known to most of us only from the opprobrious comments made by Morris Finsbury in Stevenson's novel 'The Wrong Box.'

G. TEMPLE

LUMINESCENCE

Luminescence, with particular reference to inorganic phosphors. (*British Journal of Applied Physics, Supplement No.* 4). *Pp. iv* + 120. *The Institute of Physics, London.* 1955. 25*s. net.*

Twenty-one papers presented at a symposium held in 1954 are here collected into one volume. The main subjects treated are the development of new phosphors, chiefly for the lamp industry, electroluminescence, and the nature of luminescence centres. The approaches of the authors vary from the empirical to the highly mathematical, and the techniques from simple observations of fluorescence colour to detailed crystal structure analyses. The conclusions arrived at also vary strikingly; differences of opinion are expressed on the nature of the activators giving rise to particular bands, on the valency of activator ions and their crystal sites, on the size of the luminescence centres, on the question of association of centres, and other matters. In spite of the enormous strides made in the technical development of phosphors their behaviour and interpretation remain tantalizingly obscure. Although the most powerful techniques of crystal measurement have been applied, wave-mechanical calculations attempted, and new ideas such as charge-compensation and energy-transfer injected into the subject, the parts of the puzzle have not yet fallen into place, and still await some further touches of genius.

E. J. BOWEN

STATISTICAL MECHANICS

Elements of Statistical Mechanics, *by D. ter Haar. Pp. xix* + 468. *Rinehart and Company, Inc., New York.* 1954. $8.50 *net.*

In this book the author has carried out an ambitious programme—that of presenting the main results of statistical mechanics together with some of the applications. The space at his disposal has been used efficiently, and his clear style makes for a ready understanding. Details of mathematical manipulation might have been suppressed in some places, and the mathematical appendix replaced by references only. As a whole, however, the book covers a great deal of material, and it will be valuable to research students both as a textbook and as a reference work leading to some of the more recent applications.

There are four parts, the first dealing with independent particles, the second with ensemble theory, including ensembles in quantum statistics. The third part, the longest, deals with applications, and is the most exciting section of the book. A wide range of topics is covered, including condensation phenomena, electron theory of metals, semiconductors, cooperative phenomena, and rubber elasticity. There is a chapter on statistical methods in nuclear physics and a short account of theories of the origin of the chemical elements. The last part consists of a series of appendices on such subjects as the ergodic theorem, irreversible processes, the third law, and relativistic statistics. There is an extensive bibliography, up to about 1952.

Statistical mechanics is a branch of mathematical physics having an extremely wide range of applications, extending into astrophysics and chemistry as well as into the subjects mentioned above. The present book is a welcome addition to the existing literature on this dynamic subject.

L. S. GODDARD

SUPERFLUIDITY

Superfluids, Volume II (Macroscopic Theory of Superfluid Helium), *by the late F. London. Pp. xvi* + 217. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 64*s. net.*

Superconductivity and the strikingly strange behaviour of liquid helium below the λ-point are among the most important subjects of low-temperature physics, and perhaps no other person did so much towards establishing a unified view of these two groups of phenomena as the late Professor Fritz London. The first volume of 'Superfluids', which dealt with superconductivity, appeared in 1950; this second volume, about liquid helium, was published posthumously, a few months after London's untimely death in March 1954.

The basic idea underlying this unified concept of the nature of superconductors and of liquid helium is that in these cases vanishing entropy near absolute zero is not connected with a positional order of the particles. Thus the atoms of liquid helium instead of being localized in space are, as it were, smeared out over a macroscopic region and order is brought about by a Bose-Einstein type of condensation in the momentum space. Frictionless flow in liquid helium and persistent currents in superconductors are manifestations of this ordering process with respect to momentum, and the fruitful two-fluid hypothesis is a direct outcome of these ideas.

London has written an indispensable and enjoyable book on this fascinating subject. Although this is essentially a theoretical study, experiments and their results are given their proper place and nowhere is mathematical formalism allowed to overshadow or to replace the physical meaning. It is perhaps unavoidable that in a book written round a central theme some aspects should be skimped, but the important thing is that the book brings out forcefully the now widely accepted view that the significance of superfluidity transcends the field of low-temperature physics. Indeed it seems that, as London pointed out in Volume I, the phenomena of superfluidity are pure quantum mechanisms, and 'although of macroscopic size, they are nevertheless withdrawn from the disorder of thermal agitation in essentially the same manner as is the electronic motion within atoms and molecules, in short, they are *quantum mechanisms of macroscopic scale.*'

The last word has not been said about liquid helium and superconductivity, and the theory may well take surprising turns. But London's contributions to the understanding of superfluidity is of such lasting value that, as Professor F. Bloch remarks in his foreword, any future work on this subject will still be permeated by London's spirit.

N. KURTI

ATOMIC PHYSICS

Introduction to Atomic and Nuclear Physics, *by Henry Semat. Pp.* 561.



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*Chapman and Hall Limited, London.* 1954. 50*s. net.*

This is the third edition of Semat's 'Introduction to Atomic Physics,' revised and enlarged by the addition of nuclear physics. The book has grown out of a lecture course on modern physics, and can be recommended without reservation to student and teacher alike. The material is lucidly presented in a well worked out sequence, and carefully sub-divided into sections. A good balance is preserved throughout between logical and historical development. The text is attractively printed on good paper, and the illustrations are numerous and to the point. In particular there are excellent diagrams of apparatus and many good photographs. There are also numerous explanatory diagrams to illustrate more theoretical points (for example the scattering of α-particles by nuclei and the vector model of the atom), and the important formulae are boxed-in for emphasis.

The book is divided into three parts: foundations of atomic and nuclear physics; extranuclear structure of the atom; nuclear physics (including fundamental particles). The material is up-to-date to 1953, but sacrifices neither logic nor balance to topicality, and there are very few omissions. Such important recent developments as the detection of the neutrino, positronium, mesic atoms, and X-rays, and the new heavy mesons, are all described. Perhaps some of the references to early work underlying the most recent advances are a little haphazard, and the table of nuclear spins on p. 274 is very incomplete in comparison with other collections of data in the book. But these are minor criticisms when viewed against the general excellence of the book.

M. H. L. PRYCE

### THE SENSATION OF TONE

On the Sensations of Tone, *by Hermann L. F. Helmholtz (with a new introduction by Henry Margenau). Pp. xix + 576. Dover Publications Inc., New York.* 1954. $4.95 *net.*

Scientists will need no encouragement to read or re-read Helmholtz's celebrated work, which has by now an incontestable place as one of the great classics of natural philosophy. The present edition is a reprint of the last English edition of 1885 with a new, largely biographical, introduction by Professor Henry Margenau. But there can be few musicians or music-lovers who will not learn an astonishing amount from it.

For example: how many amateurs of 12-tone music realize how much of the public's aversion to it is based not on purely intellectual habit but on the physical prejudice of the ear, accustomed to a system of tonality developed over centuries? How many librettists, and particularly translators, realize to what extent the effect of a change of vowel sound on the quality of a particular note can be predetermined? And how many orchestrators realize the physical reasons for the different qualities of instrumental tone?

Musicians should read the interesting and controversial last chapter, in conjunction with the introduction, before starting on the whole work; they will then obtain a clearer picture of the outline and terms of reference which Helmholtz has chosen. Moreover, they will find that what at first appears to be a work of formidable length and somewhat unnerving complexity is in fact extremely lucid, and intelligible even to those without any previous knowledge of physics.

MICHAEL BIRKETT

### CHEMICAL DICTIONARY

Stewart's Scientific Dictionary (*fourth edition*), *by J. R. Stewart and F. E. Spicer. Pp.* 788. *Stewart Research Laboratory, Alexandria, Va; I. R. Maxwell and Company Limited, London.* 1953. 63*s.* 6*d. net.*

This dictionary of terms used in the chemical process industries now appears in its fourth edition since 1940. While this succession of editions should be an indication that the book is fulfilling a definite need, it does nevertheless seem at the moment to be in an unsatisfactory transitory state. It is now something more than a simple dictionary, but has not yet evolved into the encyclopaedia which is apparently the ultimate aim. There is much disparity between the entries, in their length, quality, and relevance; thus among the elements neither germanium, uranium, nor titanium—to mention but three metals which now have important and well known uses—have an entry. The titanium oxide pigments, by contrast, occupy two whole pages, and this preoccupation with products relating to paints appears in many other places. The entries relate largely to American practice and in consequence a number of important trade and technical terms used in Britain and other English-speaking countries are omitted—'Terylene' and 'Paludrine' are two examples. While the title of this book is misleading, it does nevertheless give some useful information on American chemical practice.

TREVOR I. WILLIAMS

### MECHANISM OF CHEMICAL CHANGE

Atomic and Free Radical Reactions, *Volumes* 1 *and* 2 (*second edition*), *by E. W. R. Steacie. Pp. x* + 901. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. £11 4*s. net.*

The extensive studies of the course of chemical change during the past decade have shown that many apparently complex reactions take place in a series of simple steps in which the active intermediates are atoms or radicals, and the present trend in chemical kinetics is towards obtaining quantitative information of the rate and activation energies of these elementary processes. This second edition of Dr Steacie's well known monograph is therefore particularly welcome, and in bringing his work up-to-date he has rendered a great service to all interested in the mechanism of chemical change. The growth of the subject, and the vast quantity of data which has appeared since the original publication in 1946, has necessitated a complete revision of the text and an expansion to nearly twice its original size. The work, which now appears in two fairly large volumes, provides a complete summary of the rates of all atomic and free radical reactions involving organic substances reported up to June 1953, and all work in the main journals up to September 1953. A brief introductory chapter on chemical kinetics is followed (chapters II–VI) by a general discussion of experimental methods, the determination of bond dissociation energies, and the role of atoms and radicals in thermal and photochemical reactions. The second volume (chapters VII–XV) gives a systematic survey of the data relating to the rates of the individual elementary reactions for systems containing carbon and hydrogen, oxygen, nitrogen, chlorine and fluorine, bromine, iodine, sodium, other metals, and sulphur. There is a bibliography of 2086 references and a reaction index. The amount of data in the book is immense and the author will earn the gratitude of many for his clear and critical presentation of each aspect of the subject. The book will remain the standard reference work on the subject,


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but its high cost will compel the many research students and others who would treasure these volumes to use a library copy.

C. E. H. BAWN

### CHEMICAL PHARMACOLOGY

Introduction to Chemical Pharmacology, *by R. B. Barlow, with a foreword by H. R. Ing. Pp. xiv + 343. John Wiley and Sons Inc., New York; Methuen and Company Limited, London.* 1955. 35*s. net.*

A course of instruction for chemists is given in the Department of Pharmacology at Oxford by Dr H. R. Ing. The course is intended mainly for those who expect to enter the pharmaceutical industry, and covers the relation between structure and pharmacological action. It includes a practical class in methods of biological assay and of enzymology. Dr Barlow attended this course, and later worked for three years with Dr Ing; he has now written this book. It is an extremely courageous exposition of the structure-action relationship, and shows a grasp of the mechanisms of physiological action which is very surprising in a young chemist. It is well written and the presentation is interesting. After discussing the statistical treatment of biological results, the author deals with theories of narcotic action and then settles down to discuss the relationship between structure and action of analgesics like morphine, of drugs used in epilepsy, of stimulant drugs like strychnine, of local anaesthetics, of drugs like acetylcholine and nicotine, of atropine-like compounds, of curare-like compounds, of substances inhibiting cholinesterase, of adrenaline-like compounds, and of histamine-like compounds. The treatment is thorough, and well documented. The book will be of great value to many others as well as to those for whom it is specifically written, and the author is to be congratulated.

J. H. BURN

### INORGANIC CHEMISTRY

Les Gaz Inertes; l'Hydrogène—Les Halogènes, *by P. Laffitte and H. Brusset. Pp.* 396. *Masson et Cie., Paris.* 1955. *Paper covers, fcs* 3600*; bound, fcs* 4200.

In recent years inorganic chemistry has undergone a striking transition from an almost purely descriptive branch of science to a field in which all the modern developments of physics and chemistry find application. It is evident that any discussion of a chemical element or compound is complete only when the spectroscopic, structural, thermodynamic, and nuclear properties have been considered. Since the field of inorganic chemistry now embraces 101 elements a complete discussion of the whole subject is a formidable undertaking. The authors of the present volume have made a random selection of elements—the inert gases, hydrogen, and the halogens. In the discussion of these substances the authors have included enough of both the old and the new chemistry to bring out the most important features. They have not hesitated to deal with matters which may be considered outside the scope of inorganic chemistry and which are normally regarded as more appropriate to applied or organic chemistry.

The chapter concerned with the inert gases is a short one. It includes sections dealing with nuclear reactions involving α particles, the extraction of the inert gases from natural sources, the spectra of the inert gases, and the varied uses of the gases. The second chapter is devoted to the chemistry and physics of hydrogen. Sections are assigned to the structure and spectra of the hydrogen atom and the hydrogen molecule. An important discussion concerns the hydrides of the metals and the hydrogenation of various organic compounds. To complete this chapter an account is given of deuterium and its compounds, and of tritium. The final chapter is concerned with the halogens. A short account is given of element 85, the fifth halogen. The important advances in fluorine chemistry and in the chemistry of the inter-halogen compounds are given reasonable mention. This book is very readable and attractively produced. It cannot be said that it fills a long-felt want, for excellent books are now available on the subjects which the authors deal with, but it could find a useful place in most scientific libraries.

W. WARDLAW

### THE WIND

Man and the Winds, *by E. Aubert de la Rue, translated by Madge E. Thompson. Pp.* 206. *Hutchinson's Scientific and Technical Publications, London.* 1955. 18*s. net.*

It is only when gale warnings are broadcast on the radio or when we read of widespread damage done by winter storms that most of us pay any attention to the wind. In M. de la Rüe's book one reads, with some wonderment that it had not occurred to one before, how many and varied are the wind's influences. The author, who has travelled widely, keenly observing the winds in the many countries he has visited, gives a vivid account of their effect on health, the design and construction of dwellings, and on cultivation, as well as describing in detail the characteristics of most of the well known regional winds like the föhn, the chinook, the bora, and the mistral. There are chapters also on sailing ships, the wind in navigation and aviation, and the wind as a source of energy. The book is well written and illustrated and, with its many apt references, forms a useful contribution to the literature of climatology. It has been admirably translated, with many interesting notes supplementing the information given by the author, and has an adequate index.

E. W. GOLDING

### BIOLOGICAL EFFECTS OF RADIATION

Actions of Radiations on Living Cells (*second edition*), *by the late D. E. Lea. Pp.* 416. *Cambridge University Press, London.* 1955. 30*s. net.*

Lea's book, which first appeared in 1946, was immediately recognized as destined to be a classical contribution to radiation biology. The great theoretical interest of this field has always been apparent, and its practical importance, both for therapeutics and in connection with the utilization of atomic energy, is increasing continuously. It is most welcome that Lea's work, which has been out of print for some time, should now be made available again.

Lea did not attempt to review every aspect of the effects which radiations may produce on living systems. He approached the subject after a training in physics, and he concentrated his attention on those effects which seem most likely to depend on single ionizations, or small numbers of them, since these are the most susceptible to exact treatment and lead one to the fundamental processes which underlie the more complex phenomena. After a general discussion of the action of ionizing radiations on solutions, he therefore passes to such biological effects as the inactivation of viruses and the production of gene mutations and chromosome rearrangements. His treatment is in terms of the 'target' theory, and leans heavily (particularly in connection with gene mutations) on the earlier work of Timofeef-Ressovsky and his collaborators. More recent evidence, which suggests that the readiness with



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which an ionization produces an effect is very dependent on the state of the biological system at the time of irradiation, has pointed to the necessity for considerable caution in adopting this hypothesis in its simple form. Nevertheless, Lea's treatment is an indispensable basis on which later work must build. In the new edition an appendix has been added giving some of the revisions and additions which he had made in his own copy of the book, before his untimely death soon after the first edition appeared. It can hardly be claimed, however, that the book is fully up-to-date; it is valuable rather as an exposition of principles than as a summary of present knowledge. C. H. WADDINGTON

### LYSOGENIC BACTERIA

Les Bactéries Lysogènes et la Notion de Provirus, *by F. Jacob. Pp. viii + 176. Masson et Cie., Paris.* 1954. *Fcs* 800 *net.*

This monograph by Jacob is largely concerned with his studies on lysogeny in *Ps. pyocyanea*, and perhaps the most interesting contribution reported is the recognition of non-replicating agents from that species analogous to the colicines of *E. coli* strains. The main theme is, however, the behaviour of 'prophage' and the various ways in which induction (which results in the liberation of free infectious phage from the bacteria) can be provoked. There is no way by which prophage can be recognized in the lysogenic bacterium. It is not detectable serologically, and hence Jacob assumes that it is presumably in the form of nucleic acid incorporated into the genetic material of the bacterium.

This raises anew the old suggestion that phages are 'footloose' genes. In its new form the hypothesis assumes that a mutation occurring in the bacterial genome gives rise to an unstable locus which under appropriate stimulus is 'induced' to cause the production of a swarm of 'virus particles' and in the process lyse the host. Once virus particles have been produced in this fashion, they become susceptible to the interplay of mutation and survival and may evolve to the classic parasitic form of phage exemplified by T2. One may have the greatest sympathy with Jacob's view that lysogenic bacteria form the main reservoir of phages in nature without accepting this view of the phylogenesis of phages. The complete independence of immunological character and particularly the presence, in T2 at least, of a pyrimidine base not represented in bacterial deoxyribonucleic acid, suggests that we should have to go back very far indeed to find a 'common ancestor' of *E. coli* and phage T2, whether it was some proto-organism or a bacterial genome.

This, of course, is no reason whatever for not welcoming this lucid monograph on a fascinating topic which, perhaps more than any other biological theme, lends itself so freely to precise quantitative experimentation.

F. M. BURNET

### BIOLOGY OF DESERTS

Biology of Deserts, *edited by J. L. Cloudsley-Thompson. (The proceedings of a symposium on the biology of hot and cold deserts organized by the Institute of Biology.) Pp.* 224. *Institute of Biology, London.* 1954. 14*s. net.*

The Institute of Biology organized a group of discussions on the biology of deserts and the present book is the outcome. It consists of about thirty contributions, and forms a remarkable group of papers, interesting, stimulating, and tending to produce a unified picture.

The term desert covers many types of environment, for deserts differ from one another in geology, soil, climate, vegetation, and fauna. We think that the book contains no definition of a desert: if that is so, it shows wisdom.

The great majority of contributions deal with some aspect of the great desert which stretches from the Atlantic in Morocco and Mauretania to Western India and Pakistan. But there are contributions also from workers in south-west Africa and the Australian deserts and to a rather slight extent from the American deserts. The cold deserts, that is to say the Arctic and Sub-Arctic, though included in the terms of reference, receive little attention.

It is a matter of considerable interest to see the extent to which the applied biologist is studying the less severe deserts, or even putting experiments into effect in the field. One of the early contributors points out that nomads are an extremely specialized type of human being, that if they are allowed to desert their camels and become lorry drivers or labourers in oil-fields, it would probably prove impossible to resurrect the nomadic way of life. The interesting suggestion is made that these nomadic graziers could become producers of meat for the outside world, if they could be guided by radar to places where rain has recently fallen; if the land could be preserved from over-grazing; and if particular types of forage could be encouraged. The applied botanists are giving much attention to the increase of desert shrubs as grazing, for either sheep or camels, some of these plants being leguminous and others saltworts.

P. A. BUXTON

### BIOLOGICAL RECORDING METHODS

Einführung in die biologische Registriertechnik, *by Herbert Klensch. Pp. x + 222. Georg Thieme Verlag, Stuttgart.* 1954. *DM.* 33 *net.*

The author states that he has attempted in this book to give a simple introduction to the biological recording methods now generally in use. It is not clear what class of reader the book is intended for. The descriptions of the more elaborate methods, which are essentially research tools, are beyond the needs of the elementary student. But as a guide to research workers it apparently assumes that they have no knowledge of elementary physics, and have had no practical training in their degree courses; one must hope that such people are rare. The author's advocacy of simple methods, provided they are adequate, rather than elaborate, though more modern, methods, is to be commended. But in almost every section, the choice of the more elaborate methods to be described must be regarded as so incomplete as to detract seriously from the value of the book. For example, the section dealing with the measurement of the rate of fluid flow includes a description of Rein's *Thermostromuhr*, but no reference to the electromagnetic method introduced by Kolin and by Wetterer; nor, indeed, is there any mention anywhere of the bubble flowmeter or the Rotameter. Some of the very elementary material, on the other hand, might be condensed, and some platitudes omitted from the general introductory remarks; these, however, also contain some sound advice.

The book will be of value to British and American readers for its description of certain methods not commonly known to them, and for its references to European literature published in German. One is apt to neglect literature which is written in an unfamiliar language; it is unfortunate, however, that this book also suffers from the


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same trouble, there being very few references to British or American literature among the total of 421 entries in the bibliography. L. E. BAYLISS

AMINOSUGARS

Biochemistry of the Aminosugars, *by P. W. Kent and M. W. Whitehouse. Pp.* 311. *Academic Press Inc., New York; Butterworths Scientific Publications, London.* 1955. 40*s. net.*

This book represents the first attempt to bring together our knowledge of the chemistry and biological functions of these substances since the publication of Levene's monograph in 1925. The intervening years have seen far-reaching advances, and a general survey of the subject was clearly overdue.

One part of the book describes the chemical properties of the aminosugars and gives a straightforward, though critical, account of the methods for their detection, estimation, and isolation. Biochemists who encounter aminosugars in the laboratory should find these pages of much practical value.

The other part deals largely with the complex mucosubstances which contain aminosugars, ranging from those of cartilaginous tissue and the gastrointestinal tract to the gonadotropic hormones and the newly discovered receptors for the influenza virus. The purification of these substances is very difficult. The authors rightly point out that few of the products obtained so far are likely to be single molecular species and that the relationship of such products to the complexes present in living organisms is uncertain; it may be, however, that they overestimate the extent to which the state of flux in biological systems will hinder chemical progress.

The functions of mucosubstances, long ago classed as supports, protective agents, and lubricants, are discussed in the light of recent discoveries, and the growing importance of enzymic studies is well presented. In this field much is obscure, and a full assessment of the situation could be given only in a larger book. However, the present volume, which contains many references, is undoubtedly a welcome addition to biochemical literature.

E. P. ABRAHAM

FORMATION OF NATURAL PRODUCTS

The Structural Relations of Natural Products, *by R. Robinson. Pp. xi* + 150. *Oxford University Press, London.* 1955. 25*s. net.*

The first Weizmann Memorial Lectures, delivered at Rehovoth in 1953, are collected in this book. During the last forty years Sir Robert Robinson has often suggested how a complex organic substance might be built up in plants and animals. The principles of chemical reactivity determining the choice of a laboratory method are not, it is assumed, greatly different for the living cell; although the cell uses enzymes, these are more likely to catalyse facile reactions than difficult ones. Thus by considering the initial materials available to the cell, a complex molecule may be analysed structurally and possible pathways of biosynthesis outlined. The possibility of deciding between one pathway and another hardly existed until recently; the use of isotopically labelled molecules and of genetically deficient mutants now ensures increasing knowledge of biochemical processes. On the whole, the above assumption stands confirmed: most biosynthetic reactions have their laboratory counterparts.

To anyone interested in biosynthesis, this book is a treasure-chest of ideas. Perhaps some will prove incorrect in detail: none can fail to stimulate. To give a known example, the lecturer suggested twenty years ago how the four-ring structure of cholesterol might arise by multiple folding of the linear molecule of squalene. The suggestion certainly stimulated K. Bloch in his experiments proving that squalene is indeed a precursor of cholesterol, although the precise manner of folding is not that originally put forward.

The first lecture deals with several chemical types, including terpenes, steroids, carbohydrates, and flavones. The second and third lectures are devoted to alkaloids. Structural analysis suggests, with high probability, that most alkaloids originate from amino-acids or their immediate precursors; indeed, the structure of some alkaloids has been correctly predicted by assuming such an origin. With this clue the lecturer guides his audience unerringly through a maze of the most bizarre-looking structures.

The large number of pictorial formulae probably explains the high price of the book, which is produced with an excellence characteristic of the Clarendon Press. J. W. CORNFORTH

PTERIDINES

Chemistry and Biology of Pteridines (A Ciba Foundation Symposium), *edited by G. E. W. Wolstenholme and Margaret P. Cameron. Pp. xiv* + 425. *J. and A. Churchill Limited, London.* 1954. 42*s. net.*

The Ciba Foundation generously supports a practice of calling together the chief active workers in various developing fields of research, and the proceedings of these meetings are published in book form. One of the meetings in 1954 discussed 'The Chemistry and Biology of Pteridines.' The interplay between the chemical and the biological aspects was continually stressed, so that this book makes invigorating reading for workers of a wide range of interests. The chemical section contains eleven papers which not only report original chemical investigations but which also collect together stores of information on such topics as ring-opening reactions and ultra-violet spectra. In addition there are several papers devoted to the constitution of various naturally occurring pteridines. The reports of the discussions which followed bear testimony both to the interest aroused by the speakers and to the skill of the chairman, Professor Adrien Albert.

The biological sessions included several papers on antimetabolites to the naturally occurring pteridines and their mode of action, as well as some clinical studies of disordered folic acid metabolism. Further studies of the role of the citrovorum factor in cell division were among the contributions made by Dr. W. Jacobson, who was in the chair for the biological sessions.

D. H. MARRIAN

MOSSES AND LIVERWORTS

British Mosses and Liverworts, *by E. V. Watson. Pp. xvi* + 419. *Cambridge University Press, London.* 1955. 45*s. net.*

This work describes about one quarter of the British species of mosses and about one sixth of the British liverworts, being those which occur more commonly. To one who had to learn his Bryophyta from the comprehensive works of Dixon and MacVicar, the boon to the student of a handbook that is not burdened with a plethora of rarities is obvious, although the beginner is apt to fear he may have mistaken a rarer, omitted relative for the commoner species. The drawbacks inherent in any such partial treatment have been greatly minimized by the inclusion in the keys of a considerable proportion of those that occur less commonly.



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Only the test of field use by those without experience can yield a final judgment, but the author would appear to have provided a most useful handbook to initiate the novice in identifying members of these groups. Moreover, the ecological notes which he furnishes suggest the fascinating problems that the biology of these plants presents.

The text is illustrated with some two hundred informative line drawings and eighteen half-tone plates. One cannot but regret that the price may well place this work beyond the means of many of those to whom it might be most useful. E. J. SALISBURY

### PLANT PHYSIOLOGY

An Introduction to Plant Physiology (*fifth edition*), *by W. O. James. Pp. viii* + 303. *Oxford University Press, London.* 1955. 17*s.* 6*d. net.*

It is pleasant to welcome a fifth edition of James's 'Introduction to Plant Physiology.' Since it was first published in 1931 it has been a most useful textbook and one which has contrived to be modern as well as elementary. It has always been noted for lucid expression, clear illustrations, and for the large number of simple and informative experiments described. The new edition has been enlarged by 34 pages and 8 illustrations: it has been extensively re-written and reset. The physical properties of colloids and related matters have been brought together in a new chapter.

The author combines surveys of the range of behaviour—so interesting in biological material—with accounts of fundamental processes. Thus he gives tables showing the range of respiratory activity and of the respiratory quotient, and lists of the varied reactions of the plant to light and gravity. He also deals with the stepwise degradation of carbohydrate and with the organic acid cycle. How far should such topics enter elementary work? The intelligent pupil should be stimulated by such accounts: the less intelligent majority unfortunately tend to reproduce them from memory in examination papers, to the neglect of simpler and more easily understood matters. Perhaps the stimulation of the intelligent is more important. But this is an example of a continuing problem in the teaching of science to which no clear answer is apparent.

It is heartening to find the present position of such interesting topics as the first products of photosynthesis, the phototropic reaction, and flowering hormones simply and clearly stated. Dr James continues to earn the gratitude of pupil and teacher alike. M. SKENE

### VERTEBRATE ZOOLOGY

Traité de Zoologie. Anatomie, Systématique, Biologie. *Vol. XII, Vertébrés, edited by Pierre-P. Grassé. Pp.* 1145. *Masson et Cie, Paris.* 1954. *Paper covers, fcs* 9800; *bound, fcs* 10 550.

In many ways, this thirteenth volume of the great *Traité de Zoologie* edited by Professor Pierre-Paul Grassé is the most important which has yet appeared, for it deals with general questions of morphology and embryology of vertebrates. The main lines of morphogenesis, gastrulation, head-segmentation, the architecture of the central and peripheral nervous systems, the paired sense-organs, the structure of the skull, axial and appendicular skeleton, teeth, vascular and urogenital systems, are all included. There are also chapters on the chromosomes of vertebrates, and on some of the biochemical characters (sterols, phosphagens, bile-salts, haemoglobin, percentages of various cations) of many groups of animals.

There is always a danger, in large and comprehensive works of this kind, that the natural desire to effect a broad synthesis may abrade and round off some of the irregular and apparently non-conformist results of detailed and objective analysis, obtained from observation and experiments on the diversified material. This danger has been completely avoided, in Professor Grassé's textbook, by the careful selection of his collaborators and the directives on which they have worked.

The various sections are succinctly written, up-to-date, and preserve a critical attitude to controversial problems, such as for example coefficients of cephalization or the nature of the trabeculae cranii. Beautifully produced and lavishly illustrated, this work is in every way worthy of the highest traditions of French zoology.

GAVIN DE BEER

### HUMAN ANATOMY

Lehrbuch und Atlas der Anatomie des Menschen (*nineteenth edition*), *by F. Kopsch. Volume* 1, *pp.* 736; *volume* 2, *pp.* 768. *Georg Thieme Verlag, Stuttgart.* 1955. *DM* 64.50 *per volume.*

Rauber's textbook of Anatomy has passed through a long history, and though the appearance of its nineteenth edition is by no means a record for anatomical textbooks (in Britain, Gray's 'Anatomy' has reached its 31st edition), it is surely remarkable that Dr Kopsch himself has been engaged in the production of successive editions for over fifty years. German atlases of anatomy have always had a wide appeal (for example, the well known atlases of Spalteholz and Sobotta), mainly, no doubt, because the elaborate and carefully executed illustrations are so attractively reproduced. One is sometimes tempted to wonder how it is that German anatomists have at their disposal such highly skilled anatomical artists. Can it be because the publishers, having a comparatively large continental market at their disposal, are able to afford a high rate of remuneration? Possibly so, but apart from the technical efficiency of the illustrations the latter are often characterized by an accuracy of detail and a certain originality of presentation which convey an impression of the most intimate collaboration between the anatomist and his artist. The Rauber-Kopsch volumes, however, are more than an atlas, they combine an atlas and a textbook in the same production. In fact, of course, this is what all textbooks of human anatomy do, the only difference being that the illustrations are usually not so elaborately reproduced. Cunningham's 'Anatomy', for example, includes over 1200 illustrations, but since this standard book is not printed on thick art paper they have a somewhat less imposing appearance.

The question arises—do the illustrations really need to be so highly finished and so impressive as those in the volumes under review? One disadvantage is immediately obvious—the thick art paper adds enormously to the weight of the book. The current edition of Cunningham's 'Anatomy', we find, weighs nearly six pounds, while the two volumes of the Rauber-Kopsch work (which together contain about 150 fewer pages) weigh nearly eleven pounds. It can hardly be denied, also, that there is a certain misleading element in anatomical illustrations which are made to appear too realistic, for they may give the unsophisticated reader an impression of finality which is really not justified. All anatomical illustrations are, in a sense, diagrammatic representations, and the more elaborate and perfectly finished, the more likely they are to be accepted as something more than diagrams. For


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example, neurofibrillae do not really exist in the form in which they are illustrated in these volumes, nor do the terminal reticula of nerve fibres, nor do the smaller lymphatic vessels. But these disadvantages are, of course, inherent in all anatomical illustrations which attempt an aesthetic combination of accuracy with clarity, and thus to present to the student the essence of his subject in an attractive and easily assimilable form. The illustrations in the Rauber-Kopsch atlas are, from this point of view, about as excellent as they could be. The text, also, is sound as a presentation in traditional style of purely descriptive anatomy. The section on the central nervous system is perhaps the least satisfactory, for it does not incorporate some of the more recent work on fibre connections (and from this point of view is somewhat outdated), and it also includes diagrams of fibre connections which almost certainly do not exist. As a textbook for students, the work is perhaps unnecessarily long and detailed, and for most students, of course, too expensive. But as a reference book in libraries it certainly has an important place.

W. LE GROS CLARK

NUCLEAR ENGINEERING

Introduction to Nuclear Engineering, *by Raymond L. Murray. Pp. xiv + 418. George Allen and Unwin Limited, London.* 1955. 30*s. net.*

Engineering students will increasingly concern themselves with the nuclear energy field, and many will have to become acquainted with a new and rapidly developing technology and with the basic science which lies beneath it. Professor Murray's book is intended mainly for readers in this category; they are assumed to have experience, at undergraduate level, of physics, mathematics, and chemistry.

The introductory chapters, on the fundamentals of atomic and nuclear physics, have wisely been made short; good texts are now available at introductory and more advanced levels, and useful lists of references for further reading are given throughout the book. These early chapters quickly converge upon discussion of the properties and reactions of neutrons, in the velocity range appropriate to nuclear energy work, and upon nuclear fission.

The scope of the remainder, amounting to some five-sixths of the total matter, is satisfactorily broad. There is naturally an extensive treatment of nuclear reactors, but in addition there are chapters on isotope separation, radiation hazards, shielding, disposal of radioactive waste, detectors and control instruments, neutron experiments, uses of radioactive and stable isotopes, nuclear propulsion, and electrical power production by nuclear energy.

In the chapters dealing specifically with nuclear reactors, the main types are contrasted and individually described, with illustration by reference to unclassified details of existing installations and with adequate presentation of the simple theory of the processes involved. The materials of reactor construction and the heat-transfer and fluid-flow problems of reactor cooling are discussed. There are two appendices, one on reactor theory and the other a table of nuclear data. Chemical engineering aspects, such as the processing of fuel elements, are outside the scope of this book and are referred to rather little, except for a brief discussion in connection with the disposal of radioactive waste.

Security classification now covers such small and detailed areas of the subject, outside the purely military sphere, that it has interfered very little with the author's purpose. The book should suit its intended readers very well. It is clearly written, and well illustrated with diagrams and with quantitative examples. Professor Murray rightly believes that his readers should be given an overall view of the main field, even though, in the nature of things, most of them will eventually specialize rather narrowly in their daily work.

T. G. PICKAVANCE

AMERICAN MEN OF SCIENCE

American Men of Science (*ninth edition*), Volume I (Physical Sciences). *Pp.* 2180. *The Science Press, Lancaster, Pa; R. R. Bowker Company, New York.* 1955. $20.00 *net.*

The extraordinarily rapid growth of the scientific profession in the United States is emphasized by the fact that in its new edition 'American Men of Science' appears in three volumes, instead of one as previously. The number of biographies has been increased from fifty thousand, in 1949, to ninety thousand. The volume which has just appeared relates to the physical sciences only, and contains some forty-three thousand entries; the two volumes to follow will deal with the biological and the social sciences respectively.

To review a reference work of this kind in the ordinary way is impossible, but sampling of the entries indicates that, as would be expected in a cumulative work of this kind, there are no notable omissions and that in each entry a commendable amount of information is given within a short space.

The tradition of using no more than one mark of punctuation at any point makes for brevity, the first essential in a work of this kind, but perhaps not always for clarity. This is, however, only a minor criticism of a most valuable reference book. One cannot but wish that other countries would compile similar directories with comparable thoroughness.

TREVOR I. WILLIAMS

# Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

ASTRONOMY

Frontiers of Astronomy, *by Fred Hoyle. Pp. xvi + 360. William Heinemann Limited, London.* 1955. 25*s. net.*

Principes Fondamentaux de Classification Stellaire. *Pp.* 190. *Centre National de la Recherche Scientifique, Paris.* 1955. *Fcs* 1200 *net.*

Radio Astronomy, *by J. W. Pawsey and R. N. Bracewell. Pp. x + 361. Clarendon Press, Oxford.* 1955. 55*s. net.*

BIOLOGY

Animal Nutrition, *by E. J. Sheehy. Pp. viii + 732. St. Martin's Press, New York; Macmillan and Company Limited, London.* 1955. 30*s. net.*

Applied Entomology (*fifth edition*), *by H. T. Fernald and H. H. Shepard. Pp. ix + 385. McGraw-Hill Book Company Inc., New York.* 1955. $7 *net.*

Aux Confins de la Vie. Perspectives sur la Biologie des Virus, *by P. Morand. Pp.* 171. *Masson et Cie., Paris.* 1955. *Fcs* 850 *net.*



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Bird Navigation, *by G. V. T. Matthews. Pp. vi + 141. Cambridge University Press, London.* 1955. 12*s.* 6*d. net.*

Letalfaktoren, *by E. Hadorn. Pp.* 338. *Georg Thieme Verlag, Stuttgart.* 1955. *D.M.* 39 *net.*

The Life of Bacteria, *by K. V. Thimann. Pp. xviii + 775. The Macmillan Company, New York.* 1955. $12.50 *net.*

Logique et dynamique du peuplement végétal, *by M. Guinochet. Pp.* 144. *Masson et Cie., Paris.* 1955. *Fcs* 880.

The Natural History of Tsetse Flies, *by P. A. Buxton. Pp. xx + 816. H. K. Lewis and Company Limited, London.* 1955. 84*s. net.*

Primates, *edited by W. C. Osman Hill.* Part 1: Strepsirhini, *pp. xxiii + 798.* Part 2: Haplorhini, *pp. xx + 347. University Press, Edinburgh. Part* 1, 1953, £5 5*s. net. Part* 2, 1955, 63*s. net.*

Some Physiological Aspects and Consequences of Parasitism, *edited by W. A. Cole. Pp. xi + 90. Rutgers University Press, New Jersey.* 1955. $2 *net.*

La Vie des Plantes, *by A. Guillaumin, F. Moreau, and C. Moreau. Pp.* 464. *Librairie Larousse, Paris.* 1954. *Fcs* 5190 *net.*

CHEMISTRY

Analytical Chemistry. The Working Tools, *edited by C. R. N. Strouts, J. H. Gilfillan, and H. N. Wilson. In two volumes, pp. xxi + 494 and ix + 496–1067. Clarendon Press, Oxford.* 1955. £5 5*s. net per volume.*

Chemistry of the Soil, *edited by Firman E. Bear. Pp. x + 373. Reinhold Publishing Corporation, London.* 1955. 70*s. net.*

Ionography, *by H. J. McDonald. Pp. x + 268. The Year Book Publishers Inc., Chicago.* 1955. 48*s. net.*

New Methods in Analytical Chemistry, *by R. Belcher and C. L. Wilson. Pp. xii + 286. Chapman and Hall Limited, London.* 1955. 30*s. net.*

Organic Reagents for Metals, Volume 1 (*fifth edition*), *edited by W. C. Johnson. Pp. viii + 199. Hopkin and Williams Limited, Chadwell Heath, Essex.* 1955. 15*s. net.*

Organic Syntheses. Collective Volume III, *edited by E. C. Horning. Pp. x + 890. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 120*s. net.*

Outlines of Enzyme Chemistry, *by J. B. Neilands and P. K. Stumpf. Pp. x + 315. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 52*s. net.*

Papírová Chromatografie, *edited by I. M. Hais and K. Macek. Pp.* 724. *Nakladatelství Československé Akademie Věd, Prague.* 1954. *Kčs* 142 *net.*

Solvent Properties of Amphiphilic Compounds, *by P. A. Winsor. Pp. ix + 207. Butterworths Scientific Publications, London.* 1954. 40*s. net.*

GENERAL

Better Ways. Nineteen paths to higher productivity. *Pp. ix + 97. British Productivity Council, London.* 1955. 2*s.* 6*d. net.*

Cells and Societies, *by J. T. Bonner. Pp.* 234. *Princeton University Press, Princeton, New Jersey; Geoffrey Cumberlege, London.* 1955. 25*s. net.*

If You Must Write——, *by W. H. Johnson. Pp. vi + 98. Hutchinson, London.* 1955. 4*s. net.*

Life, the Great Adventure, *by J. Rostand. Pp.* 258. *Hutchinson's Scientific and Technical Publications, London.* 1955. 12*s.* 6*d. net.*

Patent Law in the Research Laboratory, *by J. K. Wise. Pp.* 145. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1955. 24*s. net.*

Precast Concrete, *by Kurt Billig. Pp. xvi + 341. Macmillan and Company Limited, London.* 1955. 32*s. net.*

Smoking and its Effects, *by S. Russ. Pp.* 144. *Hutchinson's Scientific and Technical Publications, London.* 1955. 8*s.* 6*d. net.*

GEOLOGY

Les Fossiles, *by E. Basse de Ménorvae. Pp.* 124. *Presses Universitaires de France, Paris.* 1955. *Fcs* 153.

Nuclear Geology (A Symposium on Nuclear Phenomena in the Earth Sciences), *edited by H. Faul. Pp. xi + 414. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 56*s. net.*

HISTORY OF SCIENCE

The Botany of Cook's Voyages, *by E. D. Merrill. Pp. iv + 161–384. Chronica Botanica Company, Waltham; William Dawson and Sons Limited, London.* 1954. $4.75 *net.*

Causalités et accidents de la découverte scientifique, *by R. Taton. Pp.* 172. *Masson et Cie., Paris.* 1955. *Fcs* 980.

Discoveries and Inventions of the Twentieth Century, *by J. G. Crowther. Pp. xvii + 432. Routledge and Kegan Paul Limited, London.* 1955. 30*s. net.*

MATHEMATICS

From Simple Numbers to the Calculus, *by Egmont Colerus. Pp. xi + 255. William Heinemann Limited, London.* 1955. 25*s. net.*

MEDICINE

Erreger und Überträger tropischer Krankheiten, *by R. Geigy and A. Herbig. Pp. xxiv + 472. Verlag für Recht und Gesellschaft AG., Basel.* 1955. *Swiss fcs* 80.

Le Poumon, *by A. Policard. Pp.* 264. *Masson et Cie., Paris.* 1955. *Fcs* 1500.

PHILOSOPHY

Thoughts About Life, *by F. Friedburg. Pp.* 40. *Philosophical Library, New York.* 1954. $2.50 *net.*

PHYSICS

Annual Review of Nuclear Science, Volume 4, *edited by James G. Beckerley. Pp. ix + 483. Annual Reviews Inc., Stanford, California.* 1954. $7 *net.*

Atomic Energy Research at Harwell, *by K. E. B. Jay. Pp. xii + 144. Butterworths Scientific Publications, London.* 1955. 5*s. net.*

Einführung in die Quantenelektrodynamik, *by W. Thirring. Pp. xii + 122. Franz Deuticke, Vienna.* 1955. *D.M.* 17.50 *net.*

A Guide Book to Electricity, *by J. H. M. Sykes. Pp.* 275. *Hutchinson's Scientific and Technical Publications, London.* 1955. 21*s. net.*

A Handbook of Hard Metals, *by W. Dawihl. Pp. viii + 162. Her Majesty's Stationery Office, for Department of Scientific and Industrial Research, London.* 1955. 25*s. net.*

The Laws of Nature, *by R. E. Peierls. Pp.* 284. *George Allen and Unwin Limited, London.* 1955. 21*s. net.*

Physics and Microphysics, *by Louis de Broglie. Pp.* 286. *Hutchinson's Scientific and Technical Publications, London.* 1955. 21*s. net.*

Quantum Theory of Solids, *by R. E. Peierls. Pp. viii + 146. Clarendon Press, Oxford.* 1955. 30*s. net.*

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# Notes on contributors

C. P. WHITTINGHAM,
*B.A., Ph.D.,*

Was born in London in 1922 and was educated at Owen's School, London, and St. John's College, Cambridge. After taking a research degree at Cambridge he spent a year with Professor Emerson at the University of Illinois; last year he was a visiting professor at the University of Minnesota. His researches at Cambridge have been on the physiology of photosynthesis. In collaboration with Robin Hill he has recently written a monograph on photosynthesis, and he is the author of numerous papers on this subject.

ANN WYLIE,
*M.Sc.,*

Was born in Wellington, New Zealand, in 1922 and was educated at the University of Otago. She came to England in 1947 and worked under C. D. Darlington, at the John Innes Horticultural Institution, on the cytology and history of daffodils and roses. In 1952 she joined the staff of the Botany Department of the University of Manchester, where she is now a lecturer. She is now collaborating with C. D. Darlington in preparing the second edition of Darlington and Janaki-Ammal's 'Chromosome Atlas of Cultivated Plants'.

R. SNOW,
*M.A., B.Sc., F.R.S.,*

Was born in 1897 and educated at Winchester College and, after service with the Royal Artillery in the war of 1914–18, New College, Oxford. Has been a Fellow of Magdalen College, Oxford, since 1922. His botanical researches have been principally on the response of plants to stimuli, the correlation between their growing parts, and the determination and location of leaves. In this last field he has worked mainly in collaboration with his wife.

J. N. ALDINGTON
*B.Sc., Ph.D., F.R.I.C., F.Inst.P., F.I.E.S., M.I.E.E.,*

Was born in 1905 and was educated at the Balshaws Grammar School, Leyland, the Harris Institute, Preston, and the Technical College, Blackburn. He has been with Siemens Electric Lamps and Supplies Limited since 1923, and is managing director of that firm and of Alfred Graham and Company Limited. In August 1955 he was appointed managing director of Siemens Brothers and Company Limited. He is author of various papers and articles dealing particularly with developments in electric discharge lamps. He has twice been awarded the Leon Gaster Memorial Premium for theses on fluorescent light sources and their applications and on bright light sources; he has also been awarded the Crompton Premium of the Institution of Electrical Engineers. He is a member of the National Illumination Committee of Great Britain and of the British National Committee of the International Electrotechnical Commission.

H. W. CUMMING,
*B.Sc., A.R.I.C.,*

Was born in Preston in 1921 and educated at Preston Grammar School and the Harris Technical College. Since 1940 has been engaged in research in the laboratories of Siemens Electric Lamps and Supplies Limited, particularly upon electrical discharges in gases and vapours. In 1951 was awarded the Leon Gaster Premium of the Illuminating Engineering Society.

L. J. AUDUS,
*M.A., Ph.D.,*

Was born in 1911 and was educated at the University of Cambridge. Was on the botany staff of University College, Cardiff, from 1935 until the outbreak of the last war, when he took a commission in the R.A.F.V.R. and went to Singapore in command of a radar unit. Spent the last 3½ years of the war in Japanese prison camps in the South Pacific. On demobilization, joined an Agricultural Research Council Unit of Soil Metabolism to investigate problems of weedkillers in soils. His interests extended into the fields of soil microbiology and plant growth hormones, with which his present research is concerned. In 1948 was appointed to the Hildred Carlile Professorship of Botany at Bedford College, University of London. He is the author of one book, *Plant Growth Substances* (1953), and research articles on plant respiration and plant growth hormones, particularly in relation to roots.

SIR HAROLD SPENCER JONES,
*K.B.E., M.A., Sc.D., D.Phil., Ll.D., F.R.S., F.R.S.E.,*

Has held the position of Astronomer Royal since 1933. He was born in London in 1890 and was educated at Latymer Upper School, Hammersmith, and Jesus College, Cambridge. From 1923 to 1933 he held the post of His Majesty's Astronomer at the Cape of Good Hope. He was knighted in 1943. He has received the Royal Medal of the Royal Society, the Gold Medal of the Royal Astronomical Society, the Janssen Medal of the Astronomical Society of France, the Bruce Gold Medal of the Astronomical Society of the Pacific, and the Gold Medal of the British Horological Institute. He is an Honorary Fellow of Jesus College, Cambridge, a past president of the Royal Astronomical Society, of the British Astronomical Association, of the Institute of Navigation, of the International Astronomical Union, and of the Society for Visiting Scientists. He is president of the British Horological Institute. He is a foreign member of many national academies and an honorary member of many Dominion and foreign astronomical societies.



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